

REPORT 14



SWEEP

SOIL AND WATER

ENVIRONMENTAL

ENHANCEMENT PROGRAM



PAMPA

PROGRAMME D'AMÉLIORATION

DU MILIEU PÉDOLOGIQUE

ET AQUATIQUE



SWEEP

is a \$30 million federal-provincial agreement, announced May 8, 1986, designed to improve soil and water quality in southwestern Ontario over the next five years.

PURPOSES

There are two interrelated purposes to the program; first, to reduce phosphorus loadings in the Lake Erie basin from cropland run-off; and second, to improve the productivity of southwestern Ontario agriculture by reducing or arresting soil erosion that contributes to water pollution.

BACKGROUND

The Canada-U.S. Great Lakes Water Quality Agreement called for phosphorus reductions in the Lake Erie basin of 2000 tonnes per year. SWEEP is part of the Canadian agreement, calling for reductions of 300 tonnes per year — 200 from croplands and 100 from industrial and municipal sources.



PAMPA

est une entente fédérale-provinciale de 30 millions de dollars, annoncée le 8 mai 1986, et destinée à améliorer la qualité du sol et de l'eau dans le Sud-ouest de l'Ontario.

SES BUTS

Les deux buts de PAMPA sont: en premier lieu de réduire de 200 tonnes par an d'ici 1990 le déversement dans le lac Erie de phosphore provenant des terres agricoles, et de maintenir ou d'accroître la productivité agricole du Sud-ouest de l'Ontario, en réduisant ou en empêchant l'érosion et la dégradation du sol.

SES GRANDES LIGNES

L'entente entre le Canada et les États-Unis sur la qualité de l'eau des Grands Lacs prévoyait de réduire de 2 000 tonnes par an la pollution due au phosphore dans le bassin du lac Erie. PAMPA fait partie de cette entente qui réduira cette pollution de 300 tonnes par an — 200 tonnes provenant des terres agricoles et 100 tonnes provenant de sources industrielles et municipales.

TECHNOLOGY EVALUATION AND DEVELOPMENT SUB-PROGRAM

THE EFFECT OF TERRACES ON
PHOSPHORUS MOVEMENT

FINAL REPORT

July, 1990

Prepared by:

ECOLOGISTICS LIMITED
Waterloo, Ontario

Under the Direction of:

ECOLOGICAL SERVICES FOR PLANNING LIMITED,
Guelph, Ontario - Subprogram Manager For TED

On Behalf of:

AGRICULTURE CANADA
RESEARCH STATION,
HARROW, ONTARIO N0R 1G0

Disclaimer:

The views contained herein do not necessarily reflect the views
of the Government of Canada or the SWEEP Management
Committee.

TABLE OF CONTENTS

	<u>Page</u>
EXECUTIVE SUMMARY	iv
ACKNOWLEDGMENTS	v
1.0 BACKGROUND	1
1.1 The TED Component of SWEEP	1
1.2 Use of Structures for Erosion Control	1
2.0 INTRODUCTION	3
2.1 Outline of the Proposed Study	3
2.2 Channel Terracing as a Form of Structural Erosion Control	4
3.0 THE STUDY	7
3.1 Selection of a Study Site	7
3.2 Characteristics of the Selected Site and Associated Watershed	7
3.2.1 Topography	10
3.2.2 Soils	10
3.2.3 Predicted Hydrologic Characteristics	13
3.3 Selection and Installation of Monitoring Equipment	15
3.3.1 Theoretical Description of the Monitoring Apparatus	17
3.3.1.1 The Outflow Monitoring System	17
3.3.1.2 The Inflow Monitoring System	22
3.3.1.3 The Data Acquisition System	24
3.3.2 Laboratory Testing of Apparatus	28
3.3.3 Field Installation and Testing	36
3.4 Site Monitoring	39
3.4.1 Changes Made During the Monitoring Period	41
3.4.2 Monitoring Protocol	41
3.4.3 Data Collected	42
3.5 Analysis of the Data Collected from the November 15 Runoff Event	45
3.5.1 Water Quality Data Analysis	45
3.5.2 Water Quality Data Analysis	53
3.5.3 Results	57
3.6 Computer Simulation of November 15, 1989 Runoff Event	57
3.6.1 Background	58
3.6.2 Application of HYMO	58
3.6.2.1 Model Description	58
3.6.2.2 HYMO Output for the November 15, 1989 Event	59

TABLE OF CONTENTS CONTINUED

	<u>Page</u>
3.6.3 Application of AGNPS	59
3.6.3.1 Model Description	59
3.6.3.2 AGNPS Output for the November 15, 1989 Event	60
3.6.4 Application of CREAMS	61
3.6.4.1 Model Description	61
3.6.4.2 CREAMS Output for November 15, 1989 Event	63
3.6.5 Application of SEDCAD	64
3.6.5.1 Model Description	64
3.6.5.2 SEDCAD ⁺ Output for November 15, 1989 Event	65
3.6.6 Summary of Modelling Results	65
4.0 CONCLUSIONS	72
4.1 Evaluation of the Field Monitoring Apparatus	72
4.2 Evaluation of Terraces as a Technique to Reduce Loadings to Watercourses	73
4.3 Evaluation of Existing Modelling Techniques	73
5.0 RECOMMENDATIONS	75
5.1 Recommended Changes to the Field Monitoring Apparatus	75
5.2 Recommendations for the Use of Existing Models	76
5.3 Recommendations for Designing Channel Terrace Systems	76
SELECTED REFERENCES	77

APPENDIX A: Theory and Operation of OMEGA Model FP-5300 Flowmeter

APPENDIX B: Specifications of Selected Pressure Transducer

APPENDIX C: The Data Acquisition Software (for the Campbell 21X Micrologger)

APPENDIX D: Computer Simulation Input and Output Files (diskette)

APPENDIX E: Names and Addresses of Suppliers of Selected Equipment used in Study

LIST OF TABLES

Table 3.1	Soil Laboratory Analysis	13
Table 3.2	Summary of Predicted Hydrologic Response Analysis (SCS Method)	14
Table 3.3	Rainfall Depths Corresponding to Design Storm Events of a Given Duration	15
Table 3.4	Runoff Storage Capacity of Monitored Terrace's Ponding Area	16
Table 3.5	Anticipated Operating Environment for Flowmeter	19
Table 3.6	Comparison of Characteristics of Selected Flowmeters	21
Table 3.7	Average Pond Outflow Rates During Peak Outflow Period	51
Table 3.8	Storage and Corresponding Outflow Rates Used to Construct the Hydrograph's Recession Limb	52
Table 3.9	Summary of HYMO Output for November 15, 1989 Event	59
Table 3.10	Summary of AGNPS Output for November 15, 1989 Event	61
Table 3.11	Summary of CREAMS Output for November 15, 1989 Event	63
Table 3.12	Summary of SEDCAD ⁺ Output for November 15, 1989 Event	70
Table 3.13	Summary of Modelling Results	71

LIST OF FIGURES

	<u>Page</u>
Figure 2.1 Typical Configuration of a Channel Terrace	6
Figure 3.1 Location of Study Site	8
Figure 3.2 The Watershed to be Monitored	9
Figure 3.3 Contour Map of Study Watershed	11
Figure 3.4 Soils Map of Study Watershed	12
Figure 3.5 The Outflow Monitoring System	18
Figure 3.6 Sediment Cup Details	25
Figure 3.7 A Sediment Cup Showing Filter Paper	26
Figure 3.8 Schematic of Data Acquisition System	27
Figure 3.9 The Laboratory Set-up	29
Figure 3.10 Portion of the Laboratory Set-up Beyond the Flowmeter	29
Figure 3.11 Detail of OMEGA [®] Model FP-5300 Paddlewheel Type Flowmeter	30
Figure 3.12 The Tee Connection	30
Figure 3.13 Wiring Diagram for Campbell Scientific 21X Data Acquisition System	32
Figure 3.14 Regression Analysis Results for Honeywell Model 236PC05GW Pressure Transducer	33
Figure 3.15 Developed Stage-Discharge Relationship for Standpipe Inlet	35
Figure 3.16 Preparing Site for Installation of Catchbasin	37
Figure 3.17 Installing Bottom Portion of Catchbasin	37
Figure 3.18 Interior of Catchbasin with Monitored Lateral Pipe Installed	38
Figure 3.19 Study Site Showing Base Monitoring Equipment Installed	38
Figure 3.20 Monitoring Apparatus Installed in Field (April, 1989)	40
Figure 3.21 Daily Rainfall in Study Watershed	43
Figure 3.22 Daily Sunlight Radiation Levels in Study Watershed	44
Figure 3.23 Daily Rainfall in Study Watershed for the Month of November 1989	47
Figure 3.24 Hourly Rainfall Intensities on November 15, 1989	48
Figure 3.25 Contour Map and Sediment Cup Locations for the Ponding Area	49
Figure 3.26 The Study Site Immediately Following the Runoff Event	50
Figure 3.27 A Sediment Cup within the Pond Area After an Event	50
Figure 3.28 Rainfall Intensity, Inflow and Outflow Hydrographs for November 15, 1989 Runoff Events	54
Figure 3.29 Sedimentgraph for November 15, 1989 Runoff Event	56
Figure 3.30 SEDCAD ⁺ Simulation Using MUSLE/DEPOSITS Models	66
Figure 3.31 SEDCAD ⁺ Simulation Using MUSLE/CSTRS Models	67
Figure 3.32 SEDCAD ⁺ Simulation Using SLOSS/DEPOSITS Models	68
Figure 3.33 SEDCAD ⁺ Simulation Using SLOSS/CSTRS Models	69

THE EFFECT OF TERRACES ON PHOSPHORUS MOVEMENT

EXECUTIVE SUMMARY

A variety of structural erosion control techniques have been tested and implemented as a means of reducing the rate of soil loss from agricultural land. Terracing, in particular channel terracing, is one structural approach which is gaining popularity for use on Ontario farms. Unfortunately, data which quantifies the effect terraces have on the quality of runoff water is limited. A monitoring technique is needed to gather data required to assess terrace efficiency in reducing phosphorus and sediment loads from terrace-protected lands. In order to address this need, a number of tasks were identified and undertaken in this study. Tasks included the development, selection and laboratory testing of a terrace monitoring apparatus, the field installation of the apparatus, field data collection and analysis, and computer simulation of the monitored events.

The monitoring apparatus developed and installed can best be described when viewed as being two sub-systems which are integrated through data acquisition hardware and software. The purpose of the inflow monitoring sub-system is to enable determination of the quantity and quality of runoff water entering a terrace's ponding area. The outflow monitoring system measures the level of flow exiting the terrace through the tile system and facilitates collection of water quality samples from that same water.

Laboratory tests were conducted on the monitoring apparatus prior to its field installation. Field installation was undertaken on a terraced site receiving runoff water from a 2.4 hectares watershed planted to a white bean crop. Once installed, the system was checked weekly to download the continuously-collected data and ensure that power levels for the various electronic components were maintained.

The field site was monitored for a period of eight months (April through November inclusive). This period corresponded to a relatively dry period for the study site. As a consequence, only one (1) storm event occurred which was sufficient to generate runoff and ponding at the monitored terrace. While laboratory testing instilled confidence in the operation of the monitoring apparatus, the single storm event which was available to field test the equipment identified other technical problems which went undetected during the lab testing phase. Problems encountered in the initial field test, for the most part, could be overcome relatively easily and quickly. The most difficult problem to overcome centred around the sub-zero temperatures experienced just prior to the event which is believed to have damaged the submerged pressure transducer used to measure pond water level.

As a consequence of the problems encountered in the initial field testing opportunity, the data collected for the event was incomplete. A thorough analysis, along with some extrapolation of the data which

were available however did enable formation of a complete picture of the event. For this rainstorm, which closely matched the characteristics of a 1 hour, 2 year return period storm, the terrace was found to be between 10 percent and 15 percent efficient in trapping sediment and associated phosphorus. This is much lower than the 97 percent sediment trapping efficiency measured in a previous U.S. study (Mielke, 1985). The reason for this difference is apparent when the inflow and outflow hydrographs for the event in this study are reviewed. Peak discharge rates were nearly identical for both the inflow and the outflow hydrograph suggesting little opportunity for the inflow water to pond and deposit sediment. Thus the terrace system in this situation was acting in a fashion more characteristic of a tile/catchbasin system. Further monitoring and analysis of a range of storm events is necessary before any general conclusions can be made concerning terrace trapping efficiency. Recommendations include techniques for avoiding the technical problems detected during the field test.

Three different soil erosion computer modules, AGNPS, CREAMS and SEDCAD*, all of which include algorithms for assessing the effectiveness of terracing were applied to the study site using the monitored storm event as the input rainfall. AGNPS and CREAMS give results similar to the field observed data. SEDCAD* algorithms overestimated terrace efficiency. For all models to generate reasonable results, calibration of the hydrology and sedimentology components was necessary. Results of both the monitoring and modelling aspects of the study have re-emphasized the need for designers of such systems to optimize the ponding time to facilitate the settling of sediment and yet avoid damage to the crop within the zone of temporary ponding.

ACKNOWLEDGEMENTS

The following are members of the study team who contributed their skills to the work described in this report:

- | | |
|---|-----------------------------|
| K.J. McKague (CMS - Ecologistics Limited) | - Principal Investigator |
| G.C. Watson (CMS - Ecologistics Limited) | - Programmer/Data Collector |
| T. Lobb (CMS - Ecologistics Limited--part-time) | - Field Technician |
| S.P. Mitchell (CMS- Ecologistics Limited) | - Soil Surveyor |

The above study team wish to thank the following additional participants for their valuable contribution to the study:

- | | |
|-----------------------|---|
| J. Maaskant | - Canadian distributor of Hickenbottom Drain Inlets and farm co-operator for the study, for his provision of the study site as well as his logistical support for the installation and monitoring of the study apparatus. |
| T.W. Dickinson | - An associate with CMS - Ecologistics Limited who provided guidance with respect to the equipment monitoring set-up near the outset of the study. |
| G. Schell | - TED project co-ordinator with ESP whose interest and direction in the study provided smooth and efficient co-ordination of the work. |
| W. Findlay | - Scientific advisor for TED whose practical direction and suggestions along with his prompt provision of necessary equipment and information contributed to the quality of the study. |
| The James Lobb Family | - Voluntarily gave their time, hospitality and experience to assist the study team members in their efforts. |

BACKGROUND**The TED Component of SWEEP**

The Soil and Water Environmental Enhancement Program (SWEEP) is a \$30 million federal-provincial agreement, designed to improve soil and water quality in Southwestern Ontario. To assist in achieving this goal, SWEEP has been sub-divided into a number of sub-programs, one of which is the Technology Evaluation and Development (TED) sub-program.

The TED component is centred at the federal research station at Harrow. It is directed at the field level evaluation of existing technologies, in particular, the development of new conservation methods under commercial farm conditions.

The TED sub-program is managed by Ecological Services for Planning Ltd. (ESP) of Guelph. The objectives of the TED sub-program include:

- the development, evaluation and testing of agricultural technologies which are applicable to commercial farm management systems;
- close cooperation and involvement with the farm community to ensure the relevance of research and to enhance adoption of successful technologies; and
- coordination of TED efforts with the other components of the SWEEP program to minimize duplication, to collect and share relevant economic and social data and to maximize program effectiveness by considering options for technology transfer to a wide range of farm operators.

Use of Structures for Erosion Control

Structural erosion control measures are in many cases an integral part of a landowner's comprehensive plan in addressing soil erosion and water quality concerns on his property. Ideally, the first defense against soil degradation is the adoption of tillage and cropping practices tailored to the farm enterprise involved which will maximize the period of time over which erosion-prone fields have some form of natural protective cover. Numerous situations do arise, however, in which improved cropping and tillage practices are not enough to entirely solve an erosion problem. In rolling landscapes, additional

protection is often required particularly in those portions of the field where natural surface drainage pathways are located. The results of surface water flow concentrating in these areas can be quite dramatic; especially following intense rainstorm events. Inconvenience resulting from the formation of gullies in their fields and seeing the degree of damage to their crops or property often prompts landowners to proceed with the installation of an erosion control structure, despite their relatively high initial cost, in order to prevent a future similar occurrence.

Many structural measures have been used in the past to remediate an erosion problem. Such measures generally fall into one of two general classes in terms of their effect on the concentrated runoff water they are controlling. These two general classes are:

- 1) Those structures which provide only an erosion resistant surface over which the surface water can pass without causing local damage.
- 2) Those structures which provide both an erosion resistant surface as well as a means of improving the quality of the water forming the concentrated surface flow.

Common erosion control structures which fall within this first category include: channel grade control structures, catchbasins with associated tile outlets, tile outlet protection, seepage control devices, rip rap protection and chute spillways. Items which fit the second category include: grassed waterways, field and channel terracing and grassed diversions. The key to structure effectiveness and landowner satisfaction in it's operation is the selection of the most appropriate structure for the erosion problem and farm enterprise at hand.

2.0

INTRODUCTION

2.1

Outline of the Proposed Study

The study undertaken and which is presented here was in response to Agriculture Canada's request for a proposal whose goal was to initiate formulation of an approach which would enable determination of the effect water and erosion control structural measures have on reducing sediment and phosphorus loads to receiving watercourses in Ontario. Thus the need to develop and test a methodology which could achieve the above goal was the principal requirement governing the scope of the study. The study is described as being developmental and exploratory in nature and thus was limited as follows:

- Field testing and application of the developed monitoring approach at only one site. The site would exhibit representative soils and topography normally encountered by the structure being studied.
- The structural measure would be considered primarily for its ability to control overland flow and to entrap sediment and phosphorus originating from cropland. The potential added benefit of prevention of gully erosion caused downslope by concentrated flows would not be considered.
- Monitoring and analysis should be capable of addressing both seasonal and event-related phosphorus loss including losses during the spring freshet.
- Instrumentation would be site and structure specific although the general approach with respect to system characterization, sampling requirements and analytic procedures could be transferred and adapted to a broad range of structural measures.

In order to achieve the goals and objectives of the study, a series of study tasks were developed and are as follows:

- 1) Develop Monitoring Methodology
- 2) Field Install Equipment
- 3) Monitor Site
- 4) Analyze Data Collected
- 5) Test Existing Modelling Techniques
- 6) Report on Findings

The first task involved a number of activities. Decisions were made as to the type and location of structure to be monitored. It was decided a terrace structure would be monitored for its effect on sediment and phosphorus loss. With this information at hand, development of a suitable monitoring apparatus was possible. Testing and calibration of the entire apparatus was undertaken once all components were obtained and shown to be functional.

The second task involved installing the apparatus in the field. Again all components were tested for their proper operation in the field and were altered as required to ensure correct operation. Once installed, the apparatus was then monitored weekly to maintain power levels, and possibly detect any potential problems before the arrival of a storm runoff event which would trigger the operation of the apparatus.

The purpose of the apparatus and monitoring (data collection) procedure was to collect pertinent samples from which the structure's efficiency in reducing phosphorus loads to the watercourse could be determined. An appropriate analysis on all samples collected had to be made in order to make this determination. Soils in the watershed, for instance, were analyzed to establish their textural classification, organic matter and phosphorus content. Water samples collected were analyzed to determine the total suspended solids, total phosphorus and soluble phosphorus content in the sample. A grid survey of the pond area was completed to develop a stage-storage relationship for the pond. These are just a few examples of the field data gathered to assist with determining terrace efficiency at reducing loadings. Each of the data collection tasks are discussed in more detail in the appropriate sections of this report.

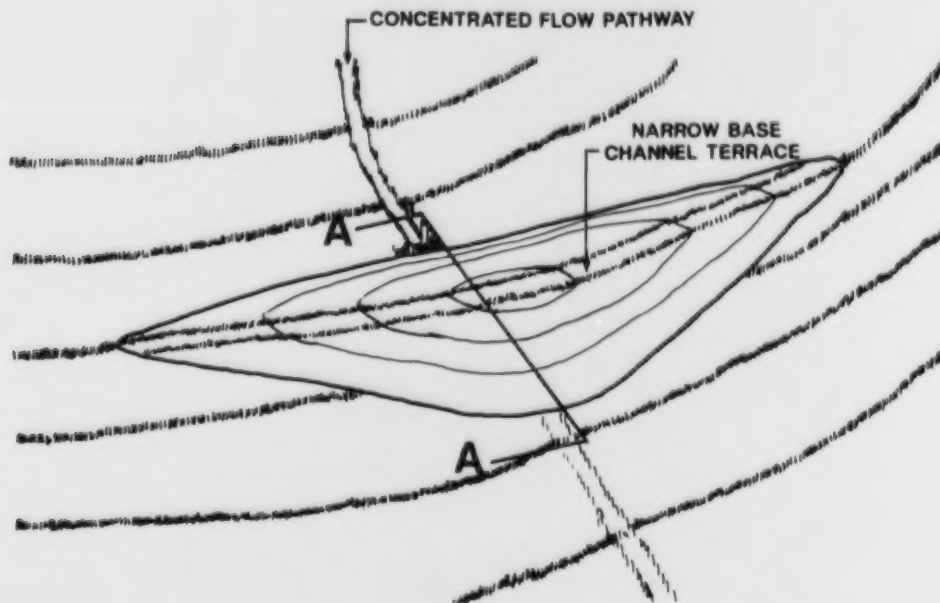
There presently exists a few computer modelling approaches which simulate the operation of erosion control structures including terraces. In order to compare their output with the field-collected data, computer simulations of the storms which generated runoff were compared with the field measured data. Results of the comparisons were then summarized. Conclusions and recommendations concerning both the modelling and the monitoring apparatus used could then be prepared for use as reference in future activities.

2.2 Channel Terracing as a Form of Structural Erosion Control

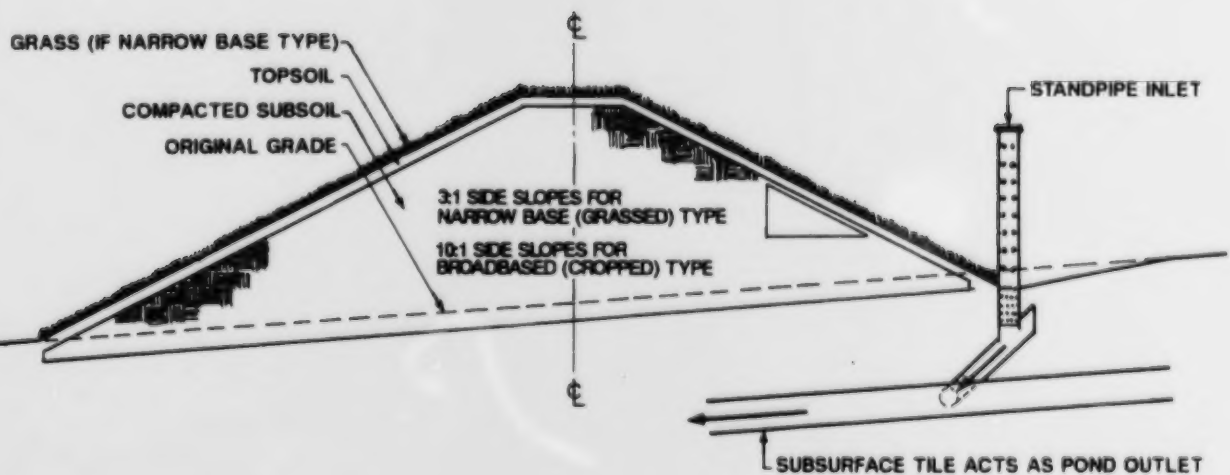
Prior to the commencement of the project, it was necessary to select the type of structural erosion control measure which would be considered for the study. Terracing, in particular channel terracing, has become much more commonplace in Ontario in the past ten years. A channel terrace, sometimes referred to as a WASCOD (Water and Sediment Control Basin), is simply an earthen berm spanning a natural draw and thus intercepts and temporarily ponds concentrated runoff water originating from small

headland watersheds. Designers of such systems usually recommend the contributing watersheds not exceed 10 ha (25 ac) in size. A standpipe inlet connected to the field's subsurface drainage system is used to drain the runoff water collected behind the berm. Thus, an erosion resistant pathway in the form of drainage tile is used to safely conduct water to the outlet. A diagram illustrating the typical layout of a channel terrace is presented in Figure 2.1. Channel terraces can be one of two types. The broadbase terrace type has relatively flat side slopes and thus allows the terrace to be farmed. The narrowbase type, while more economical to construct, is not farmed due to its characteristic steep side slope. Instead, it is seeded to a permanent grass mixture. The channel terrace not only protects the downstream portion of the concentrated flow pathway from the erosive effects of the runoff water; it also encourages improvement in the quality of the runoff water intercepted through the gradual settlement of the soil particles during the period when the water is ponded awaiting its slow release through the tile system. The channel terrace is often selected by landowners to be installed as an alternative to a grassed waterway. For many, the channel terrace is seen to have a number of advantages over the more traditional grassed waterway approach to managing surface runoff water. Both have the capability to trap or filter sediment from the runoff water, but in addition to this, the channel terrace allows for field operations to be managed more easily and often results in less land being taken out of cash crop production with the necessary planting of permanent vegetation. A literature review noted that while some work had been completed in the United States in order to determine the sediment trapping efficiency of field terraces, (Laffen, John M, et al, 1972; Mielke, L.N., 1985) no work had been undertaken to evaluate their effectiveness in Ontario conditions. Consideration was not given to the terrace's effect on phosphorus movement in the American studies. Given their growing popularity in Ontario as well as the need to begin to quantify their effectiveness as a form of erosion/pollution control, it was decided that a channel terrace system be studied in more detail.

Figure 2.1:
Typical Configuration of a Channel Terrace



(a) AERIAL VIEW



(b) SECTION A-A: TYPICAL CROSS-SECTION

THE STUDY

Selection of a Study Site

With the type of upland erosion control structure selected for analysis known, it was possible to begin selection of a study site. Criteria for site selection included the following:

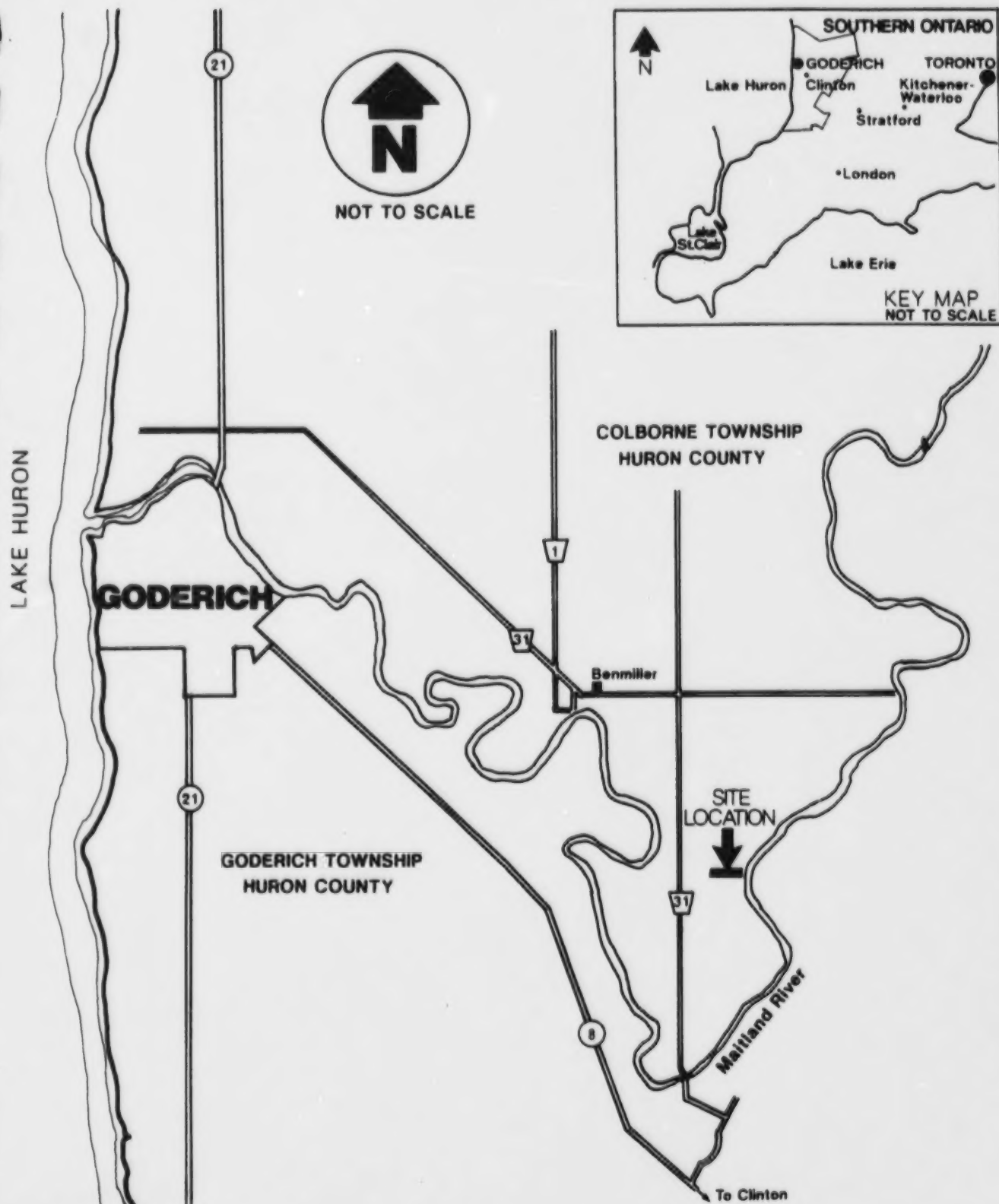
- presence of a properly designed established terrace system,
- size of the terrace's contributing watershed,
- ease of access to the site (to facilitate monitoring of the site),
- landowner interest in the study (to assist with the logistics of installation and data collection),
- uniformity of the watershed (for future modelling tasks).

A series of broadbased field terraces installed on John and Hugo Maaskant's farm located on lot 27, Maitland Concession, Colborne Township, Huron County (see Figure 3.1) were found to fit many of the requirements for a study site outlined above. This entire system, consisting of a total of 11,000 feet of berm work and numerous standpipe inlets was installed to protect a total of 110 acres of cropland. The construction began in the summer of 1982 and was completed in the summer of 1983 in response to the excessive rilling and gulying being experienced on the cropped field during extreme rainstorm events. With the terraces having been installed in 1983, the area is now stable and cropping practices have returned to normal. Access to the terraced area was relatively convenient given the number of gravel-based farm laneways on the property. Given the extent of terrace work completed on the property, a wide selection of inlets to be monitored also existed. Thus, even though the study area had been narrowed down to one site, there existed numerous inlets and associated watershed areas from which the final monitored site could be chosen following an inventory of the study area.

Characteristics of the Selected Site and Associated Watershed

Given the comprehensive nature of the field terracing work completed at the Maaskant site, the contributing watershed areas for many of the standpipe inlets were relatively small. There did exist, however, a relatively large terraced watershed on the northeast side of the property which possessed long, uniform slopes and which, atypically for the site, was drained by only two standpipe inlets. A photograph of this area is presented in Figure 3.2. The relatively large associated watershed combined with the site's uniform characteristics resulted in this portion of the 110 acre terraced site being selected for the study. A more detailed inventory of the area's characteristics could now commence.

Figure 3.1: Location of Study Site



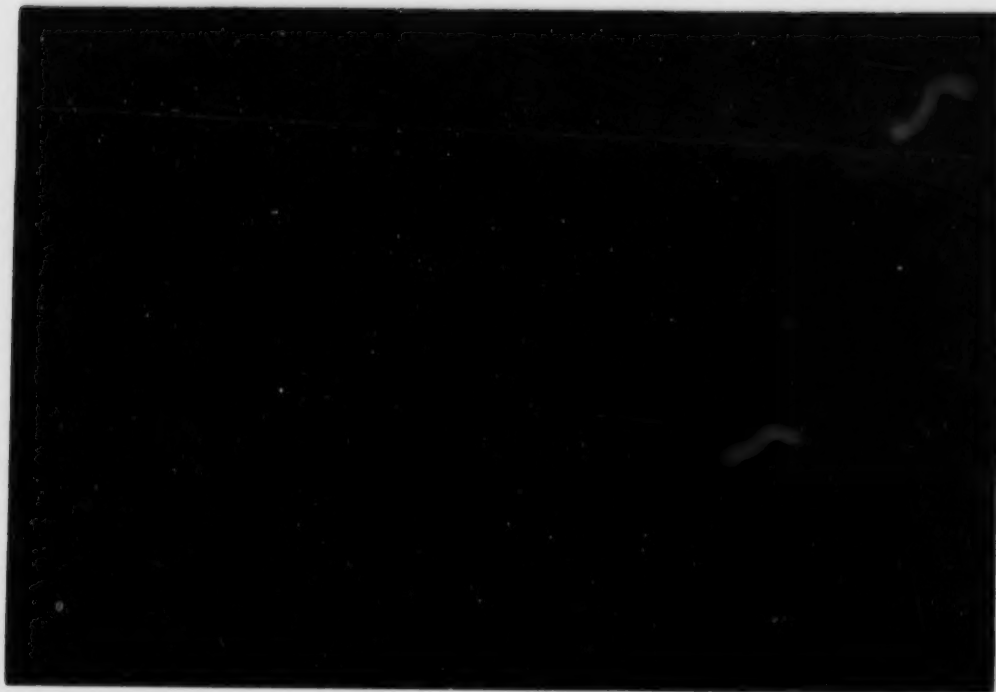


FIGURE 3.2: THE WATERSHED TO BE MONITORED

3.2.1

Topography

A 25 m X 25 m topographic grid survey of the entire watershed was completed upon the outset of the study as a means of describing the relief characteristics of the selected study area. The resulting contour map assisted in locating the boundaries of the area contributing runoff to the monitored sediment basin and thus enabled an accurate determination of watershed size. Typical local slope lengths and gradients within the watershed could also be identified and quantified from the contour map. As well, the contour map pinpointed the flow paths followed by the runoff water, assisted with soil mapping and facilitated development of a stage-storage relationship for the ponding area associated with the terrace. The contour map prepared for the study site and used as a basis for the above information is presented in Figure 3.3.

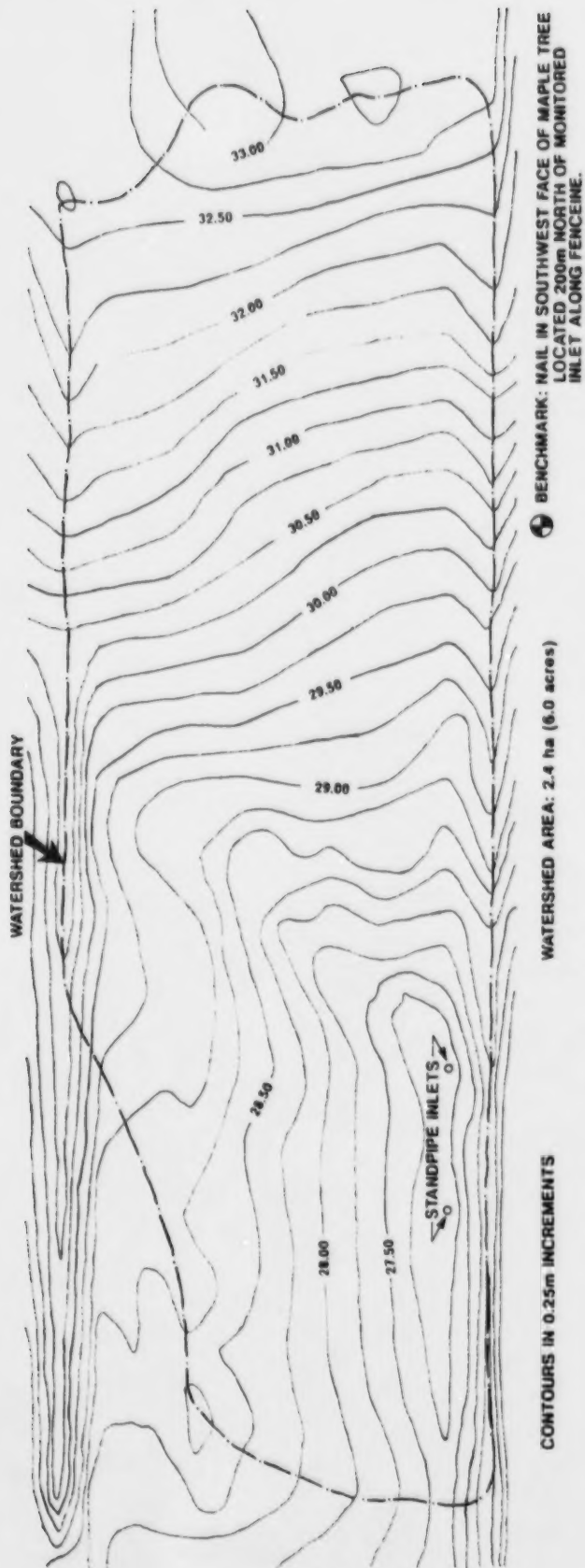
3.2.2

Soils

A soil survey which documented the soil types found in the entire watershed was completed in early November 1988. As suspected, the watershed was found to be relatively uniform with respect to soils. Soils were classed as being within the Harriston series and Listowel series depending on the soil's slope position in the watershed.

All samples taken were found to be loamy in texture. The soil profiles analyzed at the top of the watershed appeared to most closely resemble the Teeswater series. A knowledge of the history of the site would lead to the conclusion that, in constructing the terraces, the majority of the subsoil used to construct them was borrowed from this area. The result of this excavation would be a decrease in the distance measured between the soil surface and the underlying sands and gravel parent material. Thus, the soil located near the top of the watershed while originally it was likely to be Harriston loam, would be more accurately described now as being simply a disturbed profile. The soil map generated from the soil mapping activity is presented in Figure 3.4.

In addition to field mapping of the soils, representative soil samples of the surface horizon from each soil map unit were collected for laboratory analysis. A detailed textural analysis was completed along with an evaluation of the sample's organic matter content. The phosphorus content of the surface soil (top 1 cm) was also measured for future reference during the analysis and modelling stages of the study. Results of this laboratory analysis work can be found in Table 3.1

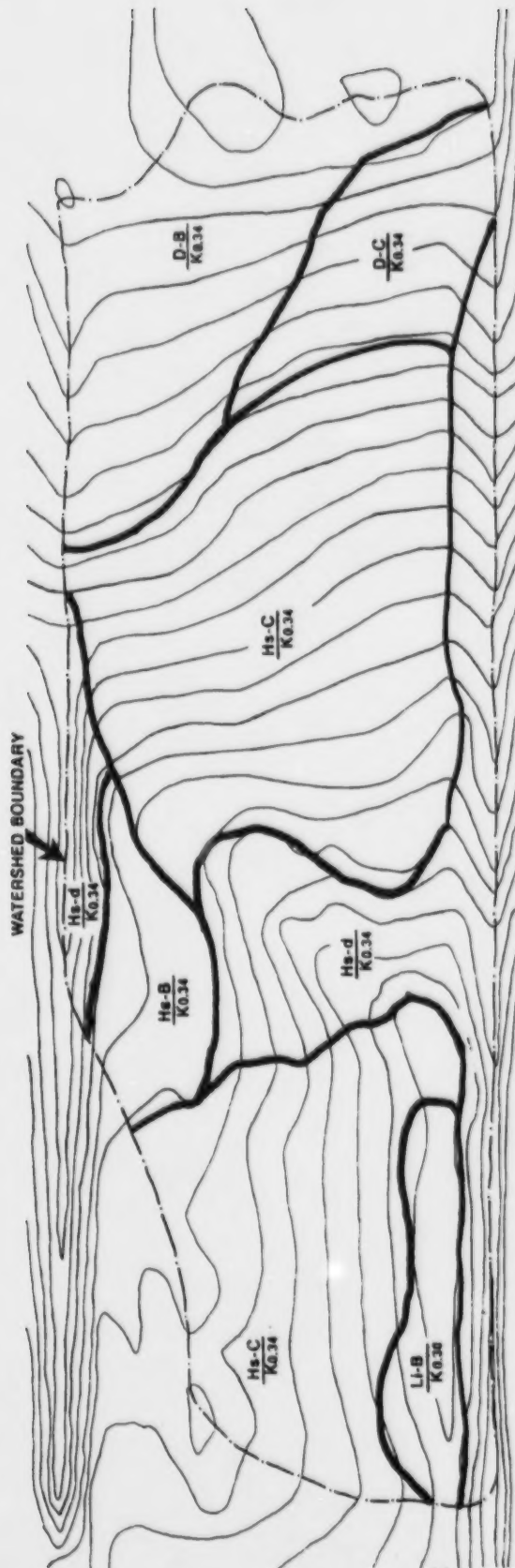


SCALE: 1 : 1,000



CMS conservation
management systems
CONSULTANTS IN SOIL CONSERVATION AND WATER MANAGEMENT

Figure 3.3:
Contour Map of Study Watershed



⊕ BENCHMARK: NAIL IN SOUTHWEST FACE OF MAPLE TREE
LOCATED 200m NORTH OF MONITORED
INLET ALONG FENCELINE.



SCALE: 1 : 1,000



CMS conservation
management systems
CONSLTANTS IN SOIL CONSERVATION AND WATER MANAGEMENT

Figure 3.4:
Soils Map of Study Watershed

LEGEND

<u>D-B</u>	SOL NAME
<u>K 0.34</u>	SLOPE CLASSIFICATION
<u>K 0.34</u>	K FACTOR VALUE
LI	LISTOWEL LOAM
Hs	HARRISTON LOAM
D	DISTURBED (Fine Sandy Loam)
-	SOIL BOUNDARY

TABLE 3.1: SOIL LABORATORY ANALYSIS

Soil Name	Texture	Particle Fractions (% by weight)									Organic Matter (%)
		GP	VCS	CS	MS	FS	VFS	SAND	SILT	CLAY	
Harriston	Loam	0.0	0.2	1.2	4.2	13.4	18.0	36.97	45.5	17.5	3.7
Listowel	Loam	0.0	1.2	1.6	3.6	9.4	12.9	28.67	49.6	21.7	4.0
Disturbed Profile	Fine Sandy Loam	0.0	0.4	0.9	5.3	25.7	20.5	52.78	34.7	12.5	2.7
Top 1 cm		Total phosphorus (mg/kg) - 629					Available phosphorus (mg/kg) - 26				

3.2.3 Predicted Hydrologic Characteristics

An initial estimate of the expected amount of runoff water was necessary to assist the study team in the selection and configuration of the site's monitoring equipment. The hydrologic model developed by the USDA Soil Conservation Service for agricultural watersheds, known as the SCS method, was used to provide this initial estimate. Numerous runs were completed using input data representative of the study site. The input data used and resulting estimates of peak flows and runoff volumes are presented in Table 3.2. A white bean crop was to be grown on the monitored watershed during the study period. This would give the area a relatively high runoff and thus erosion potential for bare soil and/or limited cover conditions would exist for a high proportion of the period. Such a condition was represented in the SCS method's runoff curve number (RCN).

The runoff volume estimates presented in Table 3.2 represent the volume of storage which would be required in a terrace's temporary ponding area in order to contain the design storm's runoff water. The actual amount of rainfall associated with the various design storms for some typical rainfall duration for the Clinton area has been interpolated from rainfall intensity-duration-frequency maps for Canada and is summarized in Table 3.3. When planning a terrace system, designers generally accommodate storage capacity for the greatest runoff volume from a 10 year return period storm.

TABLE 3.2: SUMMARY OF PREDICTED HYDROLOGIC RESPONSE ANALYSIS
(SCS Method)

Input Variables Used:

SCS RCN#	AREA	LENGTH	DELTA "H"	TIME	INTERVAL	TC
	(ha)	(m)	(m)	(hrs)	(hrs)	(hrs)
88	2.4	250	6.24	1	0.05	0.0950

Estimated Peak Flows:

DURATION (hours)	PEAK FLOW (m ³ /s)			
	(2 year)	(5 year)	(10 year)	(25 year)
0.05	0.0051	0.0429	0.0618	0.0921
0.10	0.0189	0.0762	0.1077	0.1530
0.15	0.0285	0.0928	0.1307	0.1825
0.20	0.0347	0.1015	0.1427	0.1975
0.25	0.0389	0.1061	0.1491	0.2050
0.30	0.0418	0.1083	0.1522	0.2085
0.35	0.0437	0.1092	0.1535	0.2096
0.40	0.0451	0.1093	0.1536	0.2092
0.45	0.0460	0.1088	0.1530	0.2080
0.50	0.0466	0.1080	0.1519	0.2061
0.55	0.0470	0.1070	0.1506	0.2040
0.60	0.0472	0.1058	0.1490	0.2016
0.65	0.0473	0.1046	0.1474	0.1992
0.70	0.0473	0.1034	0.1456	0.1966
0.75	0.0472	0.1021	0.1439	0.1941
0.80	0.0471	0.1008	0.1421	0.1916
0.85	0.0469	0.0966	0.1404	0.1891
0.90	0.0467	0.0983	0.1387	0.1867
0.95	0.0465	0.0971	0.1370	0.1843
1.00	0.0462	0.0959	0.1353	0.1819

Runoff Volumes Associated with Peak Flows:

	PEAK FLOW (m ³ /s)			
	(2 year)	(5 year)	(10 year)	(25 year)
Peak Flow (m ³ /s)	0.0473	0.1093	0.1536	0.2096
Duration (hours)	0.65	0.40	0.40	0.35
Storage Vol. (m ³)	87	135	190	233

Storage Volume for a 2.54 cm (1") coefficient: 610 m³

Storage Volume for a 3.81 cm (1.5") coefficient: 914 m³

TABLE 3.3: RAINFALL DEPTHS CORRESPONDING TO DESIGN STORM EVENTS OF A GIVEN DURATION

STORM DURATION (hours)	RAINFALL DEPTH (mm)			
	2 year return period	5 year return period	10 year return period	25 year return period
0.5	21	30	40	46
1.0	25	36	44	56
6.0	40	57	68	82
24	55	79	94	114

The contour or topographic data in the vicinity of the standpipe inlets was used to determine the capacity of the terrace's temporary pond. The contour-stage-storage method was used and a summary of the results is presented in Table 3.4. It can be seen from this table and the contour map that the site chosen uses two standpipe inlets in order to drain the temporary ponding area. Given the pond's capacity and the runoff predicted to occur from the contributing watershed, it was concluded that one of the inlets could be sealed off for the study period with little risk of the pond filling to the point that it would overflow into an adjacent terrace, thus affecting study results. Similarly, the sealing off of one outlet would not cause a noticeable effect on the typical operation of such a terrace system, for hydraulic calculations indicated the single outlet would be quite capable of draining the temporary storage pond within a 24 hour period - the normal design criterion for such systems.

The SCS-predicted runoff volumes for erosive storm events which could possibly occur during the one year monitoring period ranged from 87 m³ to 190 m³ (2 year to 10 year return period storm). It was in this manner that the capacity or sizing of the monitoring scheme was determined.

3.3 Selection and Installation of Monitoring Equipment

Given that a primary objective of this project was to develop a suitable monitoring apparatus for the collection of data to evaluate the efficiency of soil conservation structural systems, a significant amount of time was spent investigating equipment alternatives and the economics of various techniques. Knowing the exact type and location of the structure to be monitored allowed for specific equipment selection. It had to be kept in mind however, that the general approach used should be capable of being adapted to other terrace structures and possibly other forms of erosion control structures.

TABLE 3.4: RUNOFF STORAGE CAPACITY OF MONITORED TERRACE'S PONDING AREA

Elevation (m) ¹	Surface Area (m ²)	Average Surface Area (m ²)	Change in Height (m)	Incremental Volume	Total Surface Volume (m ³)
26.90 ²	0				0
		366	0.35	128.1	
27.25	732				128.1
		123	0.25	308.4	
27.50 ³	1735				436.5
		2306	0.25	576.6	
27.75	2878				1013.1
		3527	0.25	881.8	
27.80 ⁴	4176				1894.9

NOTES:

- ¹ Elevation values are relative to a benchmark described as a nail in the base of a maple tree located to the north of the monitored site along the property line.
- ² Approximate elevation of lowest holes in standpipe inlet (Hickenbottom). West Hickenbottom approximately 15 cm (6") lower than east Hickenbottom. East Hickenbottom was sealed off.
- ³ Peak elevation possible without storm runoff water flowing into adjacent west ponding area.
- ⁴ Crest of terrace.

Before selecting the monitoring equipment, it was necessary to determine what variables required measurement. Rainfall quantities and intensities would be necessary to determine the magnitude and erosivity of the storm event. A means of measuring the amount of runoff generated by the storm was required. The amount of sediment exiting the pond through the outlet along with a technique for determining the amount of sediment entering and/or settling in the temporary ponding area would be needed in order to evaluate the structure's trapping efficiency.

With some background research, it was concluded that the most efficient approach would entail monitoring the flowrate in the outflow pipe and periodically sampling that same water to determine its sediment and phosphorus content. In order to estimate the total sediment load to the terrace, a mass balance approach was proposed whereby the amount of sediment which was deposited in the terrace's ponding area was to be measured and added to the quantity of sediment leaving via the drainage tile to determine the total quantity of eroded soil reaching the structure. A tipping bucket rain gauge would provide the necessary rainfall data. The following section describes the components and configuration of the apparatus selected in detail.

3.3.1

Theoretical Description of the Monitoring Apparatus

To describe the monitoring apparatus chosen, it would be best to separate it into two distinct systems which, through data retrieval software and data collection protocol, function as one unit to provide the necessary data. The two distinct systems can be described as the outflow monitoring system and the inflow monitoring system. These two systems were then integrated through data acquisition hardware and software.

3.3.1.1 The Outflow Monitoring System

The purpose of the equipment associated with the outflow monitoring system is to measure tile flow and to facilitate the measurement of the quality of the water exiting the terrace pond. A sketch showing the configuration of the components of this system is presented in Figure 3.5. How such a configuration was derived follows.

Selecting an appropriate approach to flow measurement was the first step in developing the component layout presented in Figure 3.5. From experience gained in the design and implementation of channel terrace outlet systems, it was known that outlet tile lines, when connected to standpipe inlets, often surcharge. Thus, a flow measurement system was needed which was capable of measuring flowrates under both flow regimes. Measuring flow by means of weirs and flumes (open-channel conditions) was not possible for the situation at hand. Other flow measurement techniques had to be considered.

Numerous types of flowmeters are available for closed-piping systems. In general, such flow measuring devices can be categorized into four distinct groups which are as follows:

- Differential Pressure Devices (i.e. orifices, venturi tubes, pitot tubes, elbow tap meters and variable area meters),
- Positive Displacement Meters (i.e. piston, oval-gear and rotary-vane types),
- Velocity Meters (i.e. turbine, vortex shedding, electromagnetic and sonic designs),
- Mass Meters (i.e. Coriolis, thermal types),

A suitable text on flow measurement devices describes in detail the theories and principles behind each of the approaches listed above (Omega, 1988).

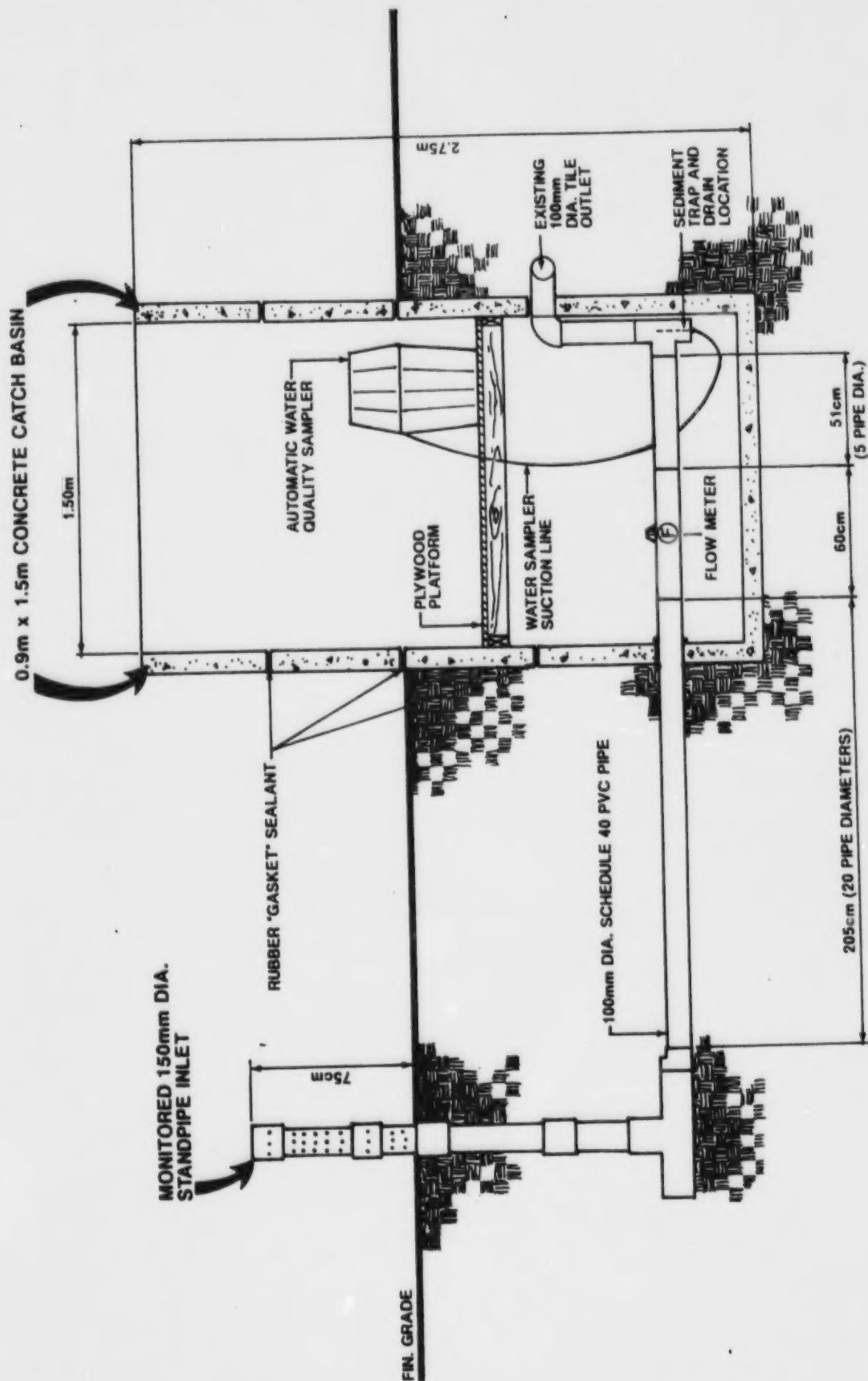


Figure 3.5: The Outflow Monitoring System

In order to select the most appropriate commercially available flowmeter for the situation at hand, the range of conditions under which the flowmeter would operate had to be determined or, at least, best estimates made. Table 3.5 summarizes the operation conditions which were anticipated. Note that one of the parameters listed in Table 3.5 was the need for the flowmeter to generate digital output. Given the remoteness and sporadic activity associated with the application, it was anticipated that a relatively automatic data retrieval system would have to be used. This could be accomplished through the use of a programmed datalogger (see section 3.3.1.3). Such data acquisition systems require digital, as opposed to analog, input.

TABLE 3.5: ANTICIPATED OPERATING ENVIRONMENT FOR FLOWMETER

PARAMETER		ANTICIPATED CONDITIONS
Pressure	Maximum	3 psi
	Minimum	0 psi
Temperature	Maximum	30°C
	Minimum	0°C (i.e. lowest temperature at which runoff is possible)
Flowrate	Maximum	50 L/s or 6.3 m/s for 100 mm diameter pipe
	Minimum	0 L/s or 0 m/s for 100 mm diameter pipe
Fluid Density (@ conditions of flow)	Maximum	1000 kg/m ³
	Minimum	996 kg/m ³
Fluid Viscosity (@ conditions of flow)	Maximum	$1.792 \times 10^3 \text{ N}\cdot\text{s}/\text{m}^2$
	Minimum	$0.801 \times 10^3 \text{ N}\cdot\text{s}/\text{m}^2$
Sufficient Straight Upstream and Downstream Run		Flexible (incorporate into layout of apparatus)
Percent Solids in Fluids		1% (10 000 ppm)
Corrosive Fluid?		no
Type of Output		voltage, current or pulse output

Knowing the criteria which the flowmeter had to meet, selection of a specific type and model could now be made. Upon reviewing flowmeter selection charts available from manufacturers, it soon became apparent that the above criterion limited the choice to vortex type, turbine type and magnetic type

flowmeters. Even here the use of magnetic type flowmeters was questionable in that they required an AC power source for their operation - something not readily available at sites where the monitoring set-up would ultimately be used. Nevertheless, commercial models of these three types of flowmeters, best suited to the application at hand, were selected and their strengths and weaknesses evaluated. Table 3.6 summarizes the characteristics of the models chosen for consideration.

Based on the information supplied by the equipment distributors, some of which is summarized in Table 3.6, it was concluded that, while no flowmeter was ideal, the paddle wheel flow sensor (OMEGA model FP-5300) appeared to be the most suitable for testing. This meter's integration into the existing drainage tile system seemed the most feasible of the three choices. It also provided the widest operating range and was quite economical. Accuracy was to the degree needed in the study. Concerns related to the use of the paddle wheel meter included its inability to measure flowrates below 2.4 L/s along with a question as to its ability to operate in water possessing a relatively high concentration of suspended solids. The manufacturers recommended these sensors not be used in fluids containing particulate matter in excess of one percent of volume (10 000 ppm). A quick review of typical sediment loadings in Ontario river systems revealed that, generally, sediment loadings there did not exceed such levels. This knowledge, combined with an awareness of the function of the terrace itself to settle out particulate matter, encouraged trying the paddle wheel sensor. Selecting the magnetic flowmeter could have, to a large extent, overcome the concerns associated with the paddle wheel sensor. Weaknesses with the magnetic flowmeter, however, were based on its need for an AC power source which would add additional cost to an already more expensive alternative. For a complete description of the theory and operation of the selected OMEGA model FP-5300 flowmeter, refer to Appendix A of this report. The remaining components of the outflow monitoring system were configured to conform to the operational needs of this flowmeter.

Full pipe conditions would be necessary for the flowmeter to function. To achieve this, a water "trap" would be designed into the outflow monitoring set-up. A head differential between the outlet side and the inlet side caused when water enters the inlet would force water through the trap. The flowrate through the trap could then be measured by the flow sensor. To ensure fully developed flow along the horizontal portion of the trap, a 200 cm long pipe (i.e. twenty diameters) would be required between the standpipe inlet and the flowmeter. Similarly, to ensure proper operation of the flowmeter, a 50 cm straight length of pipe downstream of the flowmeter would be required before exiting the trap.

The outflow monitoring set-up needed to allow for the collection of water samples from the pipe by means of an automatic water quality sampler. To facilitate this, a tee would be installed on the end of the 50 cm straight length of pipe installed behind the flowmeter. This tee connection would actually have three purposes. First, with the use of proper fittings and connectors, it would allow the suction line for

TABLE 3.6: COMPARISON OF CHARACTERISTICS OF SELECTED FLOWMETERS

FLOWMETER TYPE	FLOWMETER MODEL	SELECTED CHARACTERISTICS FOR COMPARISON							
		Power Source Required?	Upstream Diameter Required	Output Signal Type	Ease of Incorporation into Drainage Tile System	Recommended Service	Operating Range (L/s)	Typical Accuracy	Cost/Unit
Vortex	Omega FV-540L	Yes (DC)	10 to 20	4 to 20 mA dc	No	clean, dirty liquids	2.5 - 70	± 0.8% of rate	\$3000
Turbine (paddlewheel)	Omega FP-5300	Yes (DC)	5 to 10	AC with frequency and amplitude proportional to rotor rotation velocity	Yes	clean, viscous liquids	2.4 - 120	± 1.0% full scale	\$375
Magnetic	Omega FMG-5300	Yes (AC)	5	5 volt P-P square wave, or 0 - 20 mA linear, or 0 - 2 volts dc linear	Yes	clean, dirty viscous conductive liquids and slurries	1.2 - 70	± 1.0% full scale	\$2000

the water quality sampler to be inserted directly into the water being sampled just downstream of the flowmeter. Second, the tee would act as a sediment trap during periods when the water would be static in the trap. Periodic flushing of any sediment caught in the trap would be possible by removing the water quality suction line. Finally, the tee connection would direct the flowing trap water back up to the existing subsurface tile drainage system where it could exit as usual.

Access to the flowmeter and water-trap line would be necessary for installation and maintenance of this monitoring scheme. To simplify field installation and reduce costs, it was proposed that a pre-cast 1.0 meter by 1.5 meter concrete catchbasin be used to provide this needed accessibility.

3.3.1.2 The Inflow Monitoring System

With a concept formulated for the monitoring of outflow from the terrace system, attention was now directed at determining how the quantity and quality of the run-off water entering the terrace area could be measured. Estimating the quantity of run-off water stored was perceived to be a relatively simple task. It was proposed that a stilling well be installed in the terrace's temporary ponding area in the vicinity of the inlet. Pond height would then be measured either by a float and pulley apparatus or by means of a pressure transducer. Volume of water stored could be obtained from the stage-storage relationship developed from the topographic survey. To conform with the data acquisition system, the output required from whichever method chosen would have to be digital. Such output is inherent with pressure transducers. The same, however, cannot be said for the more traditional and field-proven float and pulley approach to measuring water level.

In discussions with equipment suppliers, it was learned that obtaining digital output from a float and pulley system which would conform to the data acquisition system being used was possible through the use of an incremental shaft encoder. Thus, accommodations were made to incorporate a float and pulley system into the monitoring apparatus.

While float and pulley systems are the more standard approach to measuring pond water level, the study team deemed it would be worthwhile to pursue the pressure transducer approach as well and possibly compare the two methods for their reliability. It was soon discovered that pressure transducers are relatively quite expensive, typically ranging from \$800 to \$2500 each. For this price, they were also quite accurate - more accurate than was really deemed necessary for the application at hand and significantly more accurate than a float and pulley system. At the same time they were also much more easily damaged. Thus, knowing the type of environment the transducer would be exposed to in this study (i.e. wet and dry conditions, freezing potential) it was quite possible that such a sensitive device could be made inoperable quite quickly and thus could be a rather costly approach. Through conversations with colleagues involved in selecting equipment for a similar application, it was learned that the Honeywell

Corporation produced a pressure transducer with the desired specifications for \$160. Upon receiving literature on the specific transducer, it was concluded that testing the Honeywell model 236PC05GW pressure transducer would be quite worthwhile, especially given its replacement cost. Manufacturer specifications are provided in Appendix B. With a stilling well already planned for field installation between the catchbasin and the standpipe inlet in anticipation of the use of a float and pulley system (see Figure 3.5), it was decided that the pressure transducer also be located inside the stilling well. Silicone sealant in combination with a length of flexible garden hose were both utilized to prevent pond water from contacting the transducer's housing and end cap. U-clamps to securely positioned the transducer in the stilling well. Manufacturers of the device suggested that the pressure transducer's sensing unit be kept moist at all times if possible. Consequently the bottom of the monitoring well was shaped to allow water to permanently pond when surface water accumulated in its vicinity. The transducer would then be positioned so that its sensor was submerged in this water.

Selecting an approach to measure the quality of the water in the terrace pond proved to be a more difficult task. With a technique for sampling the quality of the water exiting the pond already developed, two alternatives existed. The first would be to formulate a means of directly measuring the quality of the water entering the pond. The second alternative considered quantifying that proportion of the total sediment load which was trapped in the pond and then, using a mass balance approach, by adding this trapped amount to what left the pond through the tile system, the total sediment load to the terrace could be determined. No appropriate means for the first approach was developed which would not at the same time affect study results. Only indirect estimates made through modelling algorithms were deemed even remotely suitable and they could be applied with the second alternative anyway. Thus, effort was concentrated on developing a suitable means of estimating the amount of sediment remaining in the ponding area. A literature review revealed that past attempts made to directly measure sediment drop in a sediment pond consisted of actually measuring the depth of sediment dropped (with a ruler) at defined grid intersection points within the temporary ponding area (Laffen, John M, et al, 1972). The same level of erosion was not expected at the Clinton study site as was experienced in the Iowa terrace study. A means of quantifying the small quantities of sediment trapped was needed.

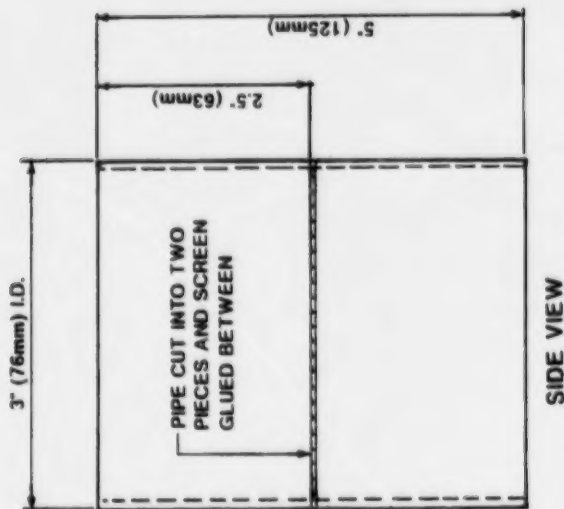
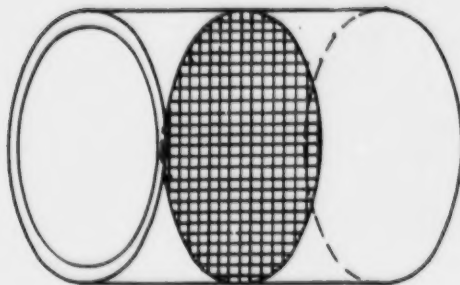
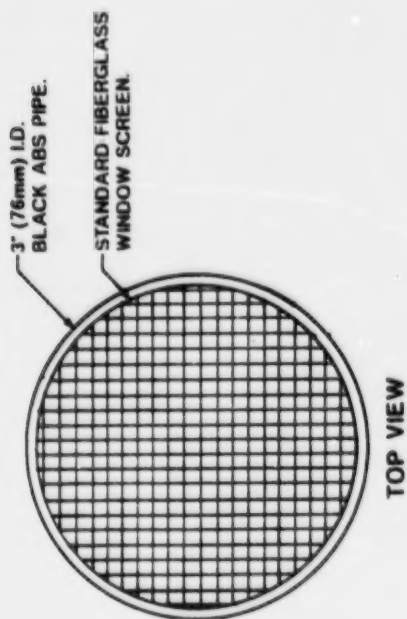
At the outset of the study, serious consideration was given to using a compound produced by Dow Chemical, and used in the past in some soil investigations called Dow Sarian Resin F-220, to coat the soil at the grid intersection points, in order to provide a barrier between the ground surface and the sediment which settled from the ponded water (Brasher, B.R., 1966). As the concept was further developed, however, numerous complications were seen. For instance, the washing action of the pond water as it receded could give quite large errors as the water either washed on adjacent untreated soil or washed off the sediment. Raindrops could have a similar adverse affect on results. Collection and

analysis was also perceived to be time-consuming and difficult. Application and mixing of the saran material itself was also difficult and relatively dangerous due to exposure to toxic fumes.

In discussing the complications associated with the use of saran with the project's Scientific Authority a suggestion was made to contact an Agriculture Canada researcher in Harrow who had been experimenting with "splash" cups which were developed in Europe for research into the effects of raindrop splash. Pursuing this suggestion revealed that the splash cup could solve many of the difficulties associated with the saran technique. A "splash" cup, which for this study has been re-named "sediment" cup is simply a 125 mm long section of 76 mm diameter ABS pipe with fibreglass window screen glued securely at the midpoint across the cup's inside diameter (Figures 3.6 and 3.7). This cup would then be placed at pre-determined grid intersection points within the ponding area by pushing them into the ground about 60 mm. Once installed, a 75 mm diameter filter paper would be placed on the cup supported by the window screen. Sediment settling out over the cup would be collected in the cup with a minimum of gain or loss from the surroundings. The sediment including the filter paper, would then be gathered, dried and weighed and the results extrapolated over the entire pond's surface area to determine the total weight of sediment dropped in the pond for the run-off event. A significant amount of time and labour is involved with this approach. It does, however, provide an improved level of accuracy over direct measurement of sediment depth for the relatively small sediment loads expected.

3.3.1.3 The Data Acquisition System

A data acquisition and process control system was required to operate and trigger the various components and to manipulate and store the appropriate output data. A Campbell Scientific model 21x micrologger was obtained for this purpose. It was more than adequate for the task at hand. A schematic showing the relationship of the various components to the micrologger is presented in Figure 3.8. A brief text description of its perceived operation, however, may also be worthwhile. To save data storage space, the datalogger would monitor only the climatic sensors initially. If upon scanning the rain gauge channel, no rainfall was detected, the system would be immediately placed in standby mode for there would be no need to check for the presence of run-off water in the pond or flow in the tile line. Temperature and radiation data, which were initially thought to be needed parameters for utilization in the modelling component of this study would be continuously monitored on a hourly basis and the value stored. If rainfall was detected however, this information along with the time of its occurrence would be sent to storage. Rainfall detection would also initiate the procedure necessary to determine if any ponding was present around the inlet or if any flow was occurring in the tile. If runoff had not yet occurred, no pond level or flow data would be sent to storage. Once a pond and/or flow has been detected, however, such information along with the time of its occurrence would be stored. Full monitoring of all systems would continue until sensors gave zero values. It was initially proposed that water samples be taken every 10 000 L based on the hydrologic evaluation of the site and the



NOTES

1. MAKE PIPE CUT AS EVEN AS POSSIBLE AND IDENTIFY THE TWO ADJACENT PIECES. BEST RESULTS ACHIEVED WITH BANDSAW.
2. CUT A SECTION OF WINDOW SCREEN. PLACE SECURELY ON ONE END OF PIPE IN PREPARATION FOR GLUE.
3. GLUE SCREEN BETWEEN THE TWO PIECES OF PIPE USING STANDARD ABS CEMENT.
4. CLAMP AFTER GLUING UNTIL GLUE HAS SET.
5. QUANTITY REQUIRED FOR STUDY - 160.

Figure 3.6: Sediment Cup Details



FIGURE 3.7: A SEDIMENT CUP SHOWING FILTER PAPER

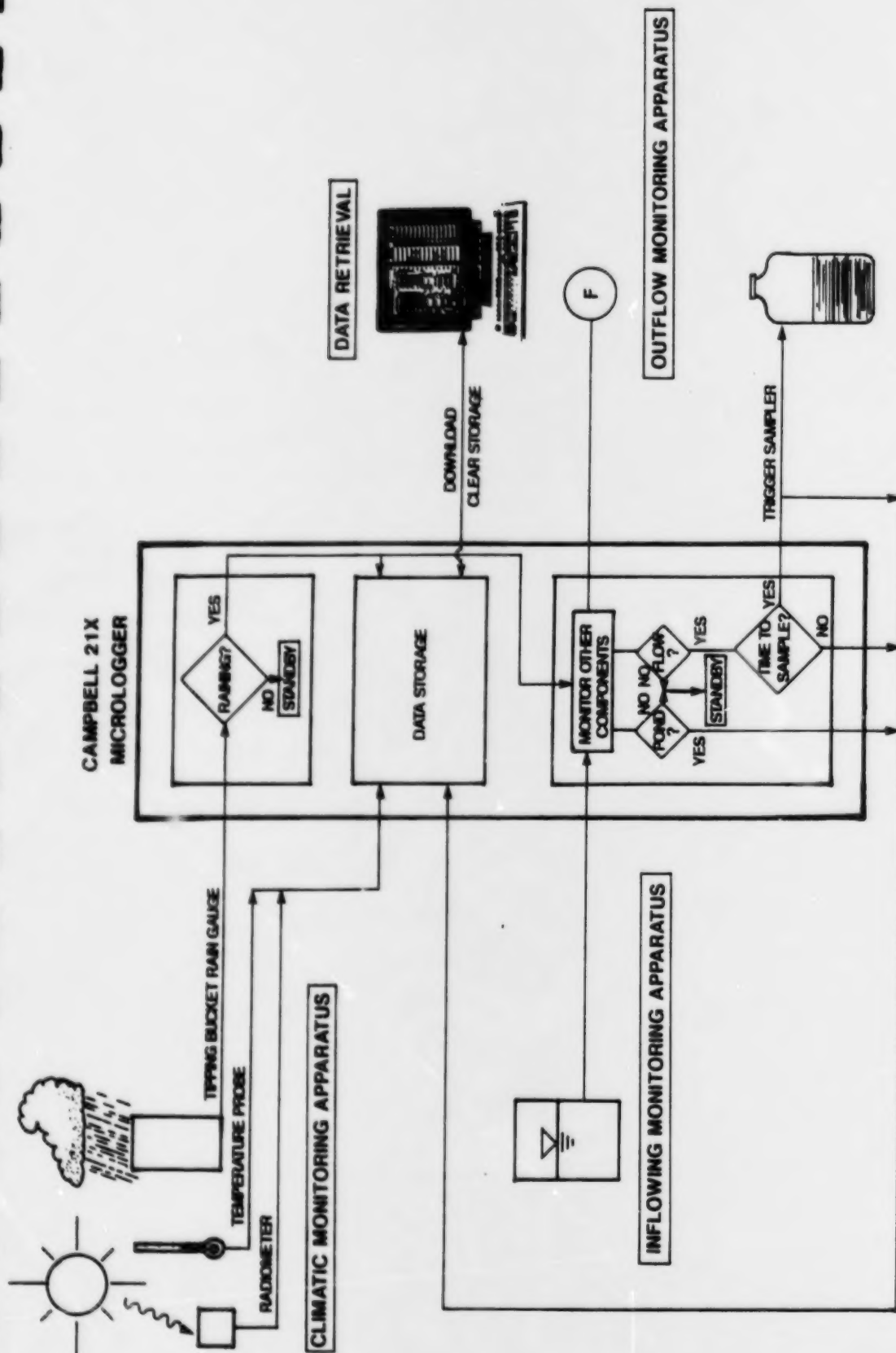


Figure 3.8: Schematic of Data Acquisition System

number of bottles available in the water quality sampler for each rain event in order to optimize the number and cross-section of samples taken during the run-off event.

It was proposed that the data collected be retrieved by downloading the micrologger through an RS-232C serial port to a portable computer on a weekly basis or following a rain event, whichever came first. This data could then be transferred to a spreadsheet for analysis and presentation purposes.

3.3.2 Laboratory Testing of Apparatus

Delays in the selection and shipment of the various components of the monitoring set-up resulted in the study team being unable to install the entire monitoring apparatus in the field in the fall of 1988. Only the base monitoring set-up, including the catchbasin and monitoring well, was installed prior to the winter period. To compensate for this loss in testing time, the study team opted to complete a thorough testing and calibration of all components of the proposed monitoring equipment in a laboratory setting prior to field installation in the spring. This approach proved to be extremely beneficial for a number of reasons. First, many practical problems associated with the proposed data acquisition approach were detected and overcome. Second, a laboratory setting made the design and calibration of the equipment quite convenient. Various flowrates and simulated pond water levels for example could be adjusted quite easily with the apparatus used for testing purposes. Also many of the irregularities associated with the data acquisition software developed for the apparatus were detected and overcome.

Figures 3.9 through to 3.12 show the set-up used in laboratory testing. This testing apparatus was constructed in such a way that it was nearly identical to what was proposed for field installation. As can be seen in Figure 3.8, first a wooden platform was built to support a 210 L plastic barrel used to simulate the pond and a pressure transducer was securely placed in the barrel to measure pond height. A Hickenbottom inlet was installed inside the barrel to simulate pond outflow. A hole was then cut in the base of the barrel to allow the Hickenbottom to be connected to the 100 mm (4") diameter outflow tile line. This tile line also acted as the water trap for the proposed flowmetering system. Once in the 100 mm (4") diameter PVC pipe, the flow passed by the OMEGA model FP-5300 flowmetering unit seen on the left-hand side of Figure 3.9 and shown in detail in Figure 3.10. The automatic water quality sampler's sampling tube was inserted into the base of the 90 degree tee extending up into the main flow of the tile line (Figure 3.11). As with the in-field set-up, the tee could also act as a sediment trap for the tile. Note that a union joint was used to allow for quick disassembly to inspect the suction line and drain the sediment trap.



FIGURE 3.9: THE LABORATORY SET-UP (left)

Showing simulated pond (barrel), platform, rain gauge, Campbell 21x micrologger, portable computer, and automatic water quality sampler. The flowmeter is also at the bottom of the picture.

FIGURE 3.10: PORTION OF THE LABORATORY SET-UP BEYOND THE FLOWMETER (below)

Water discharging into outlet barrel was recirculated by means of a submersible pump to the barrel simulating the pond seen in Figure 3.8.

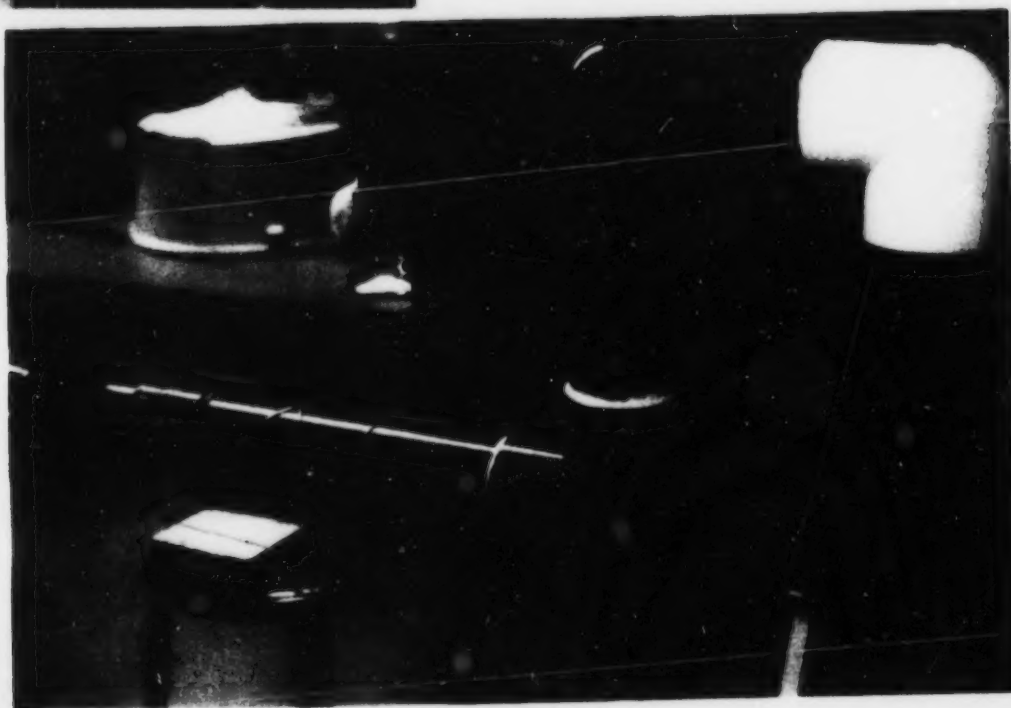
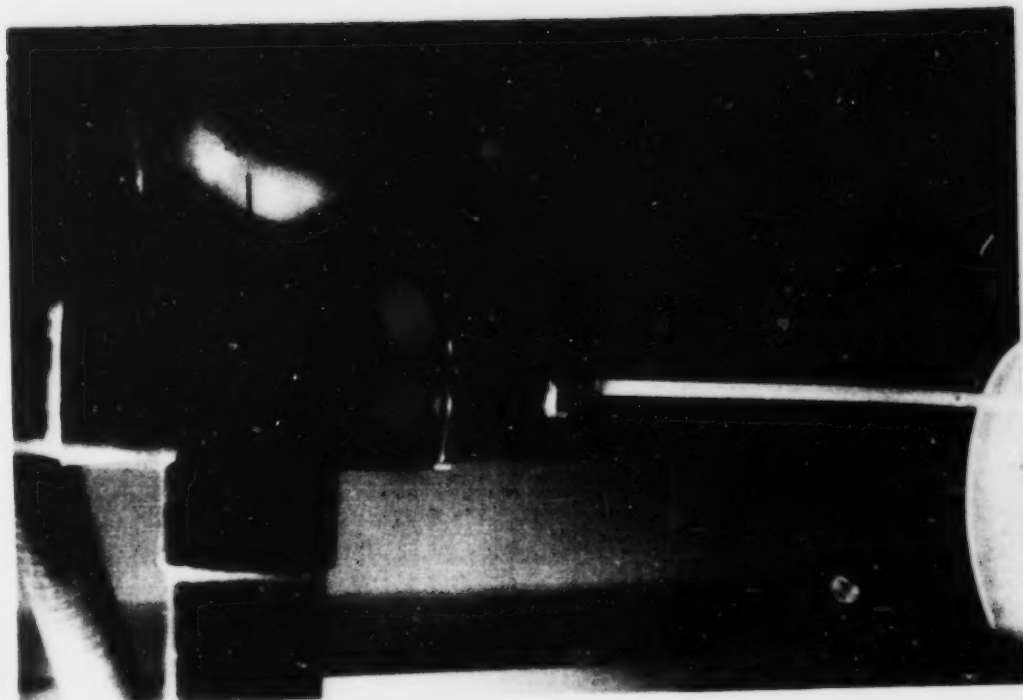




FIGURE 3.11: DETAIL OF OMEGA® MODEL FP-5300 PADDLEWHEEL TYPE FLOWMETER (above)

FIGURE 3.12: THE TEE CONNECTION (below)

Forms a sediment trap and allows for insertion of the water sampler's suction line which extends inside tee to arrow on picture.



Once flow passed all the measurement and sampling points, it was discharged into a second 210 L barrel. During testing, water was recirculated by means of a submersible pump located in the outlet barrel. Flowrates were varied in the system by adjusting a gate valve attached to the end of the submersible pump's discharge hose.

The actual wiring and testing of the various components could be completed once the lab set-up was constructed. As well, the data acquisition software used to collect and manipulate the measured data could be finalized. Components were wired to the appropriate channels on the datalogger according to their requirements and type of signal. A detailed wiring diagram for the system is given in Figure 3.13. A detailed description of the final version of the data acquisition software ultimately used is provided in Appendix C on diskette.

The economical Honeywell model 236PC05GW pressure transducer was tested first. Results of the test were quite encouraging. In the tests conducted with the proper selection of transducer multiplier and offset, differences in actual versus measured water levels were quite small with the standard error of estimation being 0.218 cm. The R-squared value for the line of best fit was 0.999 and the slope of the line was 1.0075. A graphical representation of the regression analysis showing 90 percent and 95 percent confidence limits is presented in Figure 3.14. Errors in pond height measurements were greater on the lower readings. They were, however, still within a centimetre of the actual value, allowing them to compare quite favourably with the accuracy of a float and pulley system.

It was originally proposed that a float and pulley system incorporating an incremental shaft encoder also be tested. At the time the lab tests were conducted however, the specific shaft encoder needed for integration into the existing data acquisition system was still not commercially available. In fact, it was not available from the supplier until about June 1989. Even then, cost of the digital float and pulley system was considerably higher than that of the pressure transducer. Given the success of the laboratory tests on the pressure transducer, it was decided not to consider a back-up system other than the purchase of a second transducer in the event the existing one was damaged in the field.

Next to be tested was the Omega model FP-5300 flowmeter. As mentioned previously, flowrates were adjusted by means of a gate valve attached to the pump's discharge hose. Flowrates were measured volumetrically and where possible were further checked by reviewing the water pump's rated performance curve. Flowmeter readings were then compared with these measured values. Results showed flowmeter readings to be quite inconsistent when rates were below 2.4 L/s. This verified the manufacturer's recommendation that the flowmeter be used to measure flows having average velocities between the range of 0.3 m/s and 15 m/s. With the monitoring apparatus having a 100 mm (4") diameter pipe configuration, this translates to a minimum flow of 2.4 L/s being necessary before the

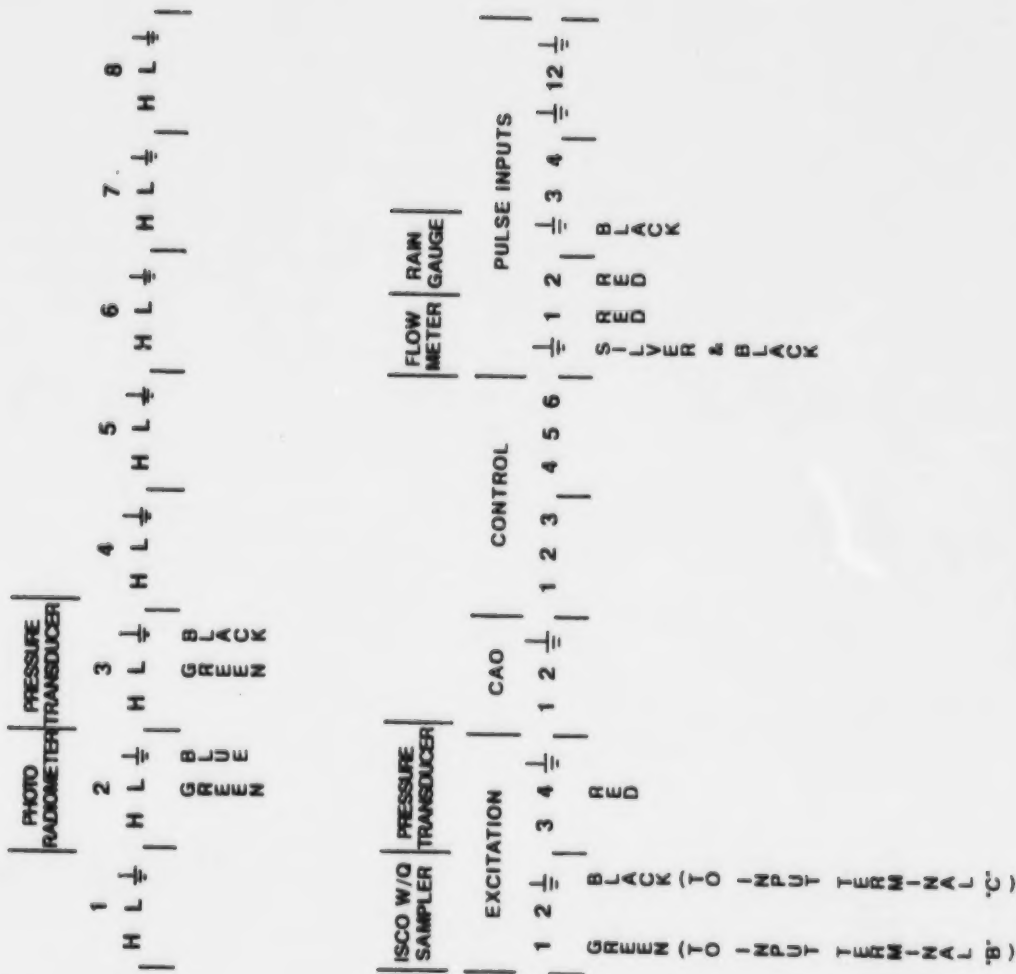
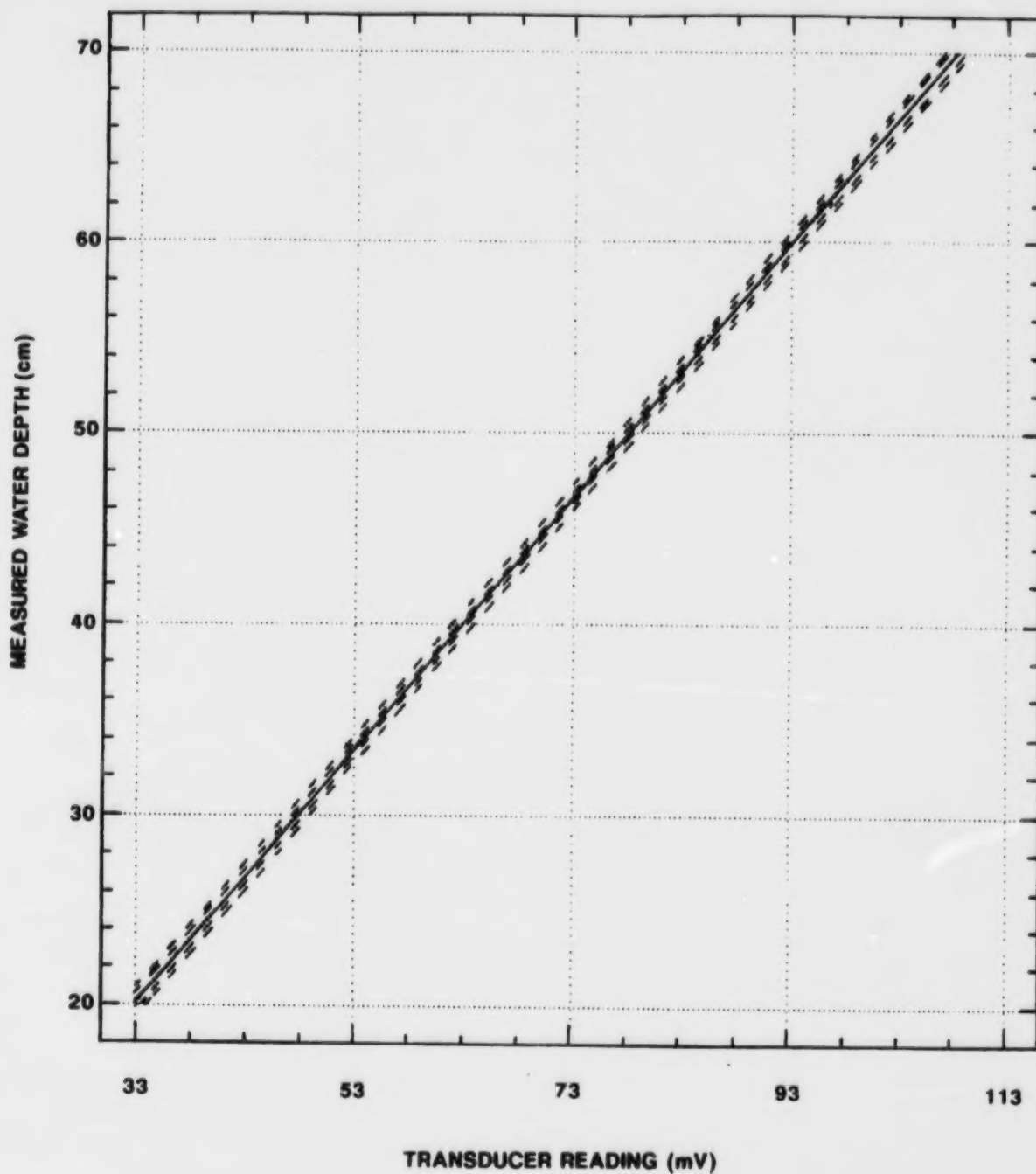


Figure 3.13: Wiring Diagram for Campbell Scientific 21X Data Acquisition System

**Figure 3.14: Regression Analysis Results for Honeywell
Model 236PC05GW Pressure Transducer**



meter is operating within its recommended range. Although attempts were made, it was not possible to develop even a non-linear relationship for the flowmeter to measure flows less than 2.4 L/s.

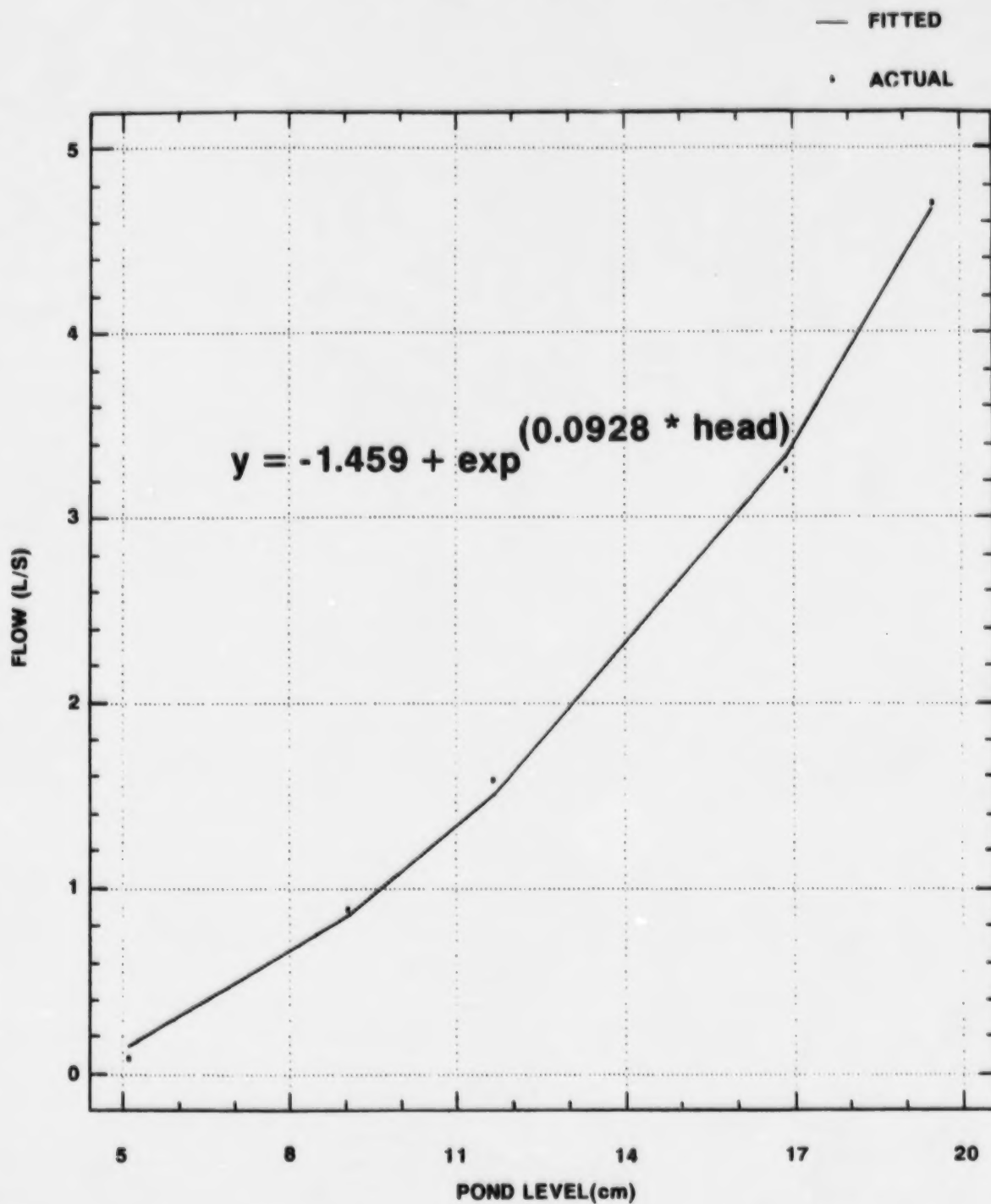
To measure flow below 2.4 L/s, an alternative method was developed which used the pond water depth reading and considered the inflow characteristics of a Hickenbottom inlet. An equation relating pond head to flowrate was derived and entered into the datalogger's data acquisition program.

A graphical representation of the final head-discharge relationship obtained, which also shows laboratory measured points, is presented in Figure 3.15. The shape of the curve in Figure 3.15 was found to be nearly identical to the shape of the performance curve developed for a 150 mm (6") diameter Hickenbottom inlet during tests at the University of Guelph (Sheehan D. and W.T. Dickinson, 1987). Thus a high degree of confidence existed in the developed function. The R-squared value for the relationship was 0.999. In programming the data acquisition system, it was decided that in order to provide a safety factor, flows less than 4.0 L/s would be measured using the above-derived function. Flows over 4.0 L/s would then be measured directly by the flowmeter. Measuring the low flows in this manner was considered appropriate given that at such low flowrates the outlet tile would not as yet be surcharging. The flowmeter would be taking flow measurements by the time pressure flow conditions existed in the outlet tile.

The rain gauge was quickly checked to ensure its accuracy and proper operation. A 25 ml pipette was used to add a known volume of water to the rain gauge. The rain gauge was found to be operating properly.

Triggering the automatic water quality sampler was accomplished primarily through the micrologger's data acquisition software. Subroutines were written which kept a running total of the volume of water passing through the drainage tile. The acquisition system was initially set in such a manner that once 10,000 L of water passed through the tile, the micrologger would instruct the water sampler to take a 200 ml water sample. Later, this volume was reduced to 2000 L passing per 500 ml sample taken due to the lower than predicted runoff levels. This procedure was then to be repeated at equal volume increments until no flow in the tile line was detected. Laboratory testing revealed that the sampler was indeed being triggered simply by connecting the triggering wires from the datalogger to flowmeter input terminals B and C on the ISCO model 2700 automatic water quality sampler. More than one sample was not taken in the lab; an oversight which proved costly later in the study.

**Figure 3.15: Developed Stage-Discharge Relationship
for Standpipe Inlet**



With laboratory testing complete and all the programming errors thought to have been eliminated from the system, the apparatus was ready for field installation. Installation was actually undertaken in two stages. The base monitoring equipment including the catchbasin, subsurface tile and related connections and the stilling well were all installed in the fall of 1988. Steps in the installation of the base equipment are shown in the pictures presented in Figures 3.18 through 3.19. Construction began by locating the subsurface outlet tile in relation to the existing Hickenbottom inlet. Next, the area requiring excavation was stripped of its topsoil for later replacement. A hole was then excavated for the catchbasin and the various sections of the catchbasin set in place with mortar placed between each section. The lateral monitoring pipe was then inserted through the pre-formed holes in the catchbasin. Many of the tile line components were joined using PVC glue a few days previously to ensure a watertight seal. Others, by necessity, had to be joined in the field. Care was given to ensure a proper fit and PVC glue was used on all joints. The only difficulties encountered were at the joint between the PVC tile and the outlet pipe. Grouting around the hole in the catchbasin, however, stopped the leaking here. All other joints proved to be watertight as well. A static water level was being maintained in the Hickenbottom drop-pipe section. The excavated area was then backfilled and topsoil replaced. The extra subsoil material was used to form a block to the west between the monitored ponding area and an adjacent ponding area. The second inlet located in the watershed was sealed off at this time as well.

While no leaks were found along joints in the monitored pipe itself, water did leak slowly into the catchbasin through the cracks located between the catchbasin sections. The mortar was not providing a sufficient seal. Numerous measures were attempted during the winter of 1989 to arrest these leaks such as the liberal application of "Water Stop" and fibreglass sealant. All attempts proved futile. It was eventually decided to install a small gas-powered water pump in the catchbasin to allow periodic pumping of the collected water. This would only be an inconvenience and would not affect data collection or the results. For the more accessible above-ground catchbasin seams, a rubber gasket was installed in the event that ponded water reached the seam level. This gasket appeared to be quite effective at providing a watertight seal and is recommended along the below-ground seams as well, provided it is applied at the time of initial installation. Finally, to add additional height to the catchbasin, a third 60 cm high section was added to the top in the early spring of 1989 prior to the installation of any electronic equipment. The extra height was added to eliminate any possibility of ponded water overtopping the catchbasin and damaging the electronic equipment stored inside.

It can be seen from Figure 3.19 that a 400 mm (16") diameter stilling well was installed between the Hickenbottom and the catchbasin to accommodate the pressure transducer and the anticipated float and



FIGURE 3.16: PREPARING SITE FOR INSTALLATION OF CATCHBASIN



FIGURE 3.17: INSTALLING BOTTOM PORTION OF CATCHBASIN



FIGURE 3.18: INTERIOR OF CATCHBASIN WITH MONITORED LATERAL PIPE INSTALLED



FIGURE 3.19: STUDY SITE SHOWING BASE MONITORING EQUIPMENT INSTALLED

pulley water level recording system. A shelter was placed on top of the stilling well to provide a suitable place for the Campbell 21X datalogger upon its arrival.

The electronic equipment was installed at the site on March 29, 1989. With much of the testing completed in the laboratory, only minor adjustments had to be made in the field. First, the value of the offset for the pressure transducer had to be measured in order to relate the pond's water depth reading to the height of water on the inlet. With the availability of water caused by the leak in the catchbasin, this task proved to be quite easy. Water was pumped from the catchbasin to the area surrounding the inlet and stilling well to a depth where water was just starting to trickle into the Hickenbottom. The depth of water at this level was read and then incorporated into the offset value embedded in the data acquisition program. All other electronic components were simply placed in position, tested for output and wired accordingly (See Figure 3.13). A plywood platform built inside the catchbasin provided a floor for the water quality sampler ensuring that it would remain dry. A platform was also built for the rain gauge and fastened to the outside of the catchbasin. The final monitored installation as it appeared in April of 1989 is shown in Figure 3.20.

More time was required to position the sediment cups than was needed to install the electronic equipment. To complete this task, a 6.1 m (20') square grid was staked out in the ponding area. This spacing was chosen for it matched the landowner's planter equipment row spacing thus making their operation and removal more convenient. Stakes were also set around the perimeter of the grid to aid in cup re-installation following tillage operations in the spring. Enough cups were used to cover a surface area that would be inundated by water if a pond depth of 0.9 m (3') (at the outlet) was to occur. By monitoring the site throughout the 1989 growing season a number of minor layout adjustments were made to the initial monitoring layout in an attempt to improve its operation.

3.4 Site Monitoring

The data acquisition equipment was monitored and the data it collected retrieved from March 29, 1989, until November 20, 1989. The original contract anticipated the monitoring period would end in July 1989. Due to the dry spring and summer weather in the Clinton area during 1989, a contract extension was granted to extend the monitoring through the fall period. The lack of significant runoff events throughout the entire 1989 season severely limited the study team's ability to detect problems specifically related to the field-applied situation leaving little room for error. In fact, there was really only one runoff event for the entire season. It occurred on November 15, 1989. Even without numerous testing events however, some problems were detected and the appropriate modifications were made.

FIGURE 3.20: MONITORING APPARATUS AS INSTALLED IN FIELD (APRIL, 1989)



A few minor field-related problems were encountered and remedied during the monitoring period, despite the lack of runoff events. For example, it soon became apparent that weights would need to be placed on the filter papers in the sediment cups, especially with the dry weather conditions, for the wind was blowing the filter paper out of a number of the cups. To simplify the weighing procedure, steel nuts were purchased and placed in each sediment cup. The nuts were relatively uniform in weight. Consequently, their weight could be easily subtracted from the total weight of the filter paper following a runoff and sediment settling event. The other changes made were primarily a result of lowering expectations as to the amount of runoff water which would be generated by the watershed during a storm event. For instance, seeing the unlikelihood of an extreme runoff event occurring, the water quality sampling procedure was altered. Instead of collecting a 200 ml sample every 2000 L, and thus filling one sample bottle every 10,000 L, the sampler was directed to take a 500 ml sample every 2000 L, thus filling one sample bottle every 4000 L. It was also noticed, particularly during the spring months, that the disturbed ground around the catchbasin, stilling well and Hickenbottom was still settling. This settlement altered the calibrated offset for the pressure transducer and so the value had to be checked and changed as required periodically.

The sediment cups were removed and replaced twice during the study period. Once was for seedbed preparation and planting and once to accommodate the harvest operation. Following the bean harvest, sediment cups were re-aligned into a 33 m (10') grid layout. This resulted in coverage of a surface area that would be completely inundated by water with only a 45 cm (1.5') water depth measured at the Hickenbottom Inlet.

Monitoring of the site consisted of a weekly inspection of the equipment, checking and/or replacing batteries and downloading the data collected for that week to the portable computer. Downloading to the computer proved to be an extremely efficient procedure. If a storm event suspected of having the potential to generate runoff occurred, the site was checked by the study team member stationed in the area to determine if water quality samples and sediment cup samples needed to be collected and prepared. Usually, the local study team member, especially towards the end of the study, also visited the site during the storm to see if any ponding was occurring in the event the monitoring system was not detecting such an occurrence. A comparison was made between the rainfall measured at the study site by the installed apparatus and the rainfall measured by a rain gauge at the local study team member's home located 5 miles away as a general check to ensure the rain gauge was working and thus able to trigger the data collection procedure.

The rechargeable battery on the ISCO water quality sampler lost its charge quickly when operating in cold weather conditions. Consequently it was replaced weekly with a fully charged battery when temperatures dipped below 10°C.

As mentioned previously, there was only one storm giving a runoff event throughout the entire season which facilitated testing of not only the apparatus but also the requirements of data collection. The processing of the water samples was to follow a specific procedure. Three samples from each 1 L bottle collected were to be prepared for laboratory analysis. First, a 500 ml sample taken from the 1 L bottle was to be separated for the purpose of determining the total suspended solids in the sample. A second 250 ml sample taken from the same 1 L bottle was to be prepared and preserved with 50 percent sulphuric acid in order to test for total phosphorus in the water. The remainder of the 1 L bottle was to be vacuum filtered and treated with 50 percent sulphuric acid in order to provide a sample for determining the total dissolved orthophosphate in the water. For the few samples that were processed, the procedure worked quite efficiently.

Collecting the filter papers from the sediment cups was a slow, although effective procedure. Each sample was placed in a bag and the grid co-ordinate was marked on each bag with a permanent marker. Analyzing the results also proved to be slow as time was required to allow the samples to dry. Oven drying would have shortened the time required for this procedure. Weighing each sample was a simple task. With the experience gained to date, no changes would be made to the procedures used in retrieving the data from the field, preparing the water samples and collecting the sediment cup contents.

3.4.3 Data Collected

Due to the lack of significant runoff events, few data were collected. The record of rainfall for the site is available for the entire period. Radiation levels are also available for most of the period, except for a short time when the radiometer was not functioning properly. Both daily rainfall and daily radiation levels are graphically presented in Figure 3.21 and Figure 3.22 respectively. Despite assurances from the supplier, the temperature probe was found to be incompatible with the Campbell 21X micrologger at an early stage in the field monitoring period. It was concluded that the temperature information would not be particularly advantageous for the modelling tasks and so was abandoned in order to conserve datalogger memory space. In its place, temperature values from a local weather station were used.

As can be seen in Figure 3.21, the largest storm occurred in early August. Also evident from the graph is the low antecedent moisture conditions which existed at the outset of this storm. Consequently, runoff

Figure 3.21: Daily Rainfall in Study Watershed

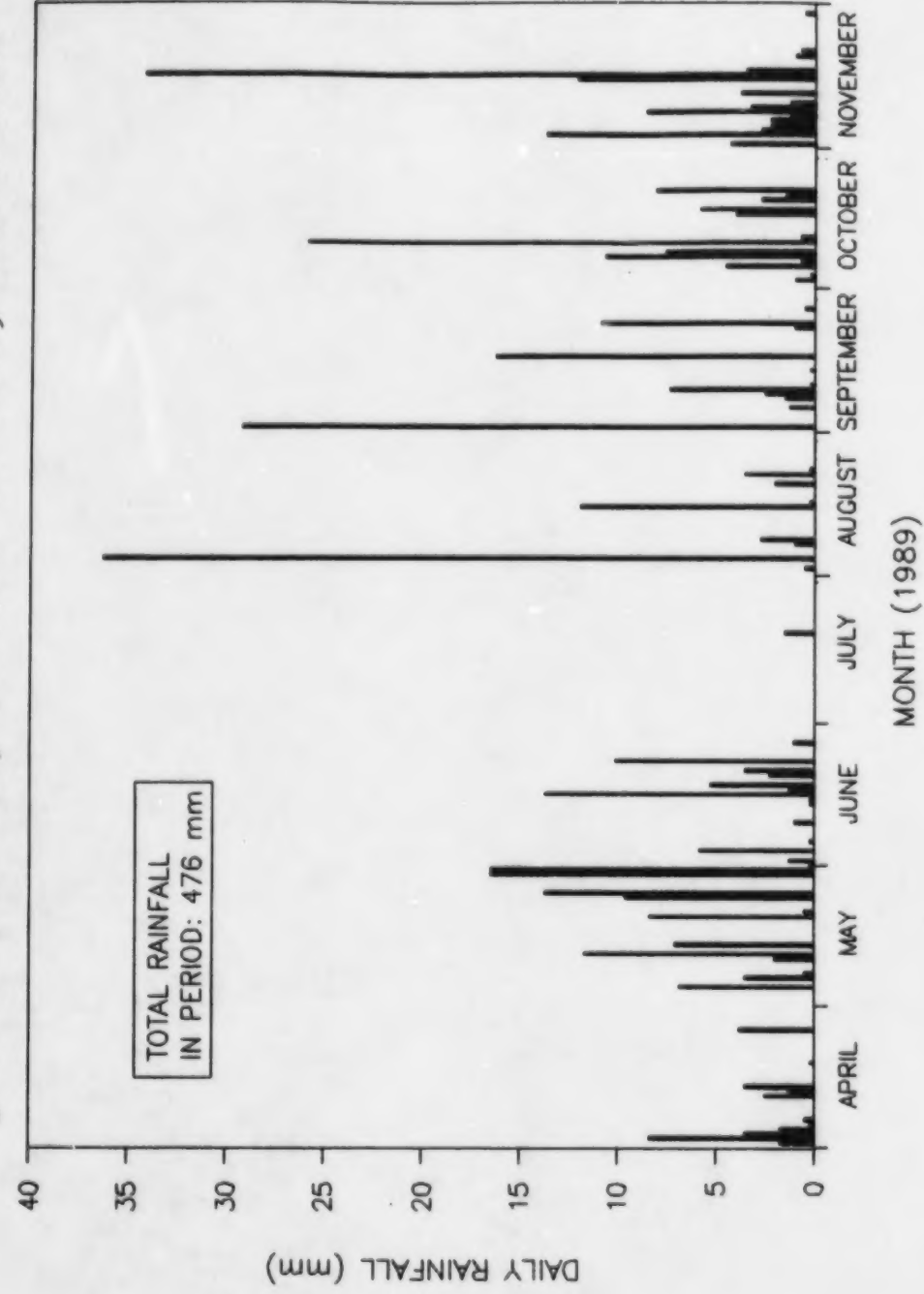
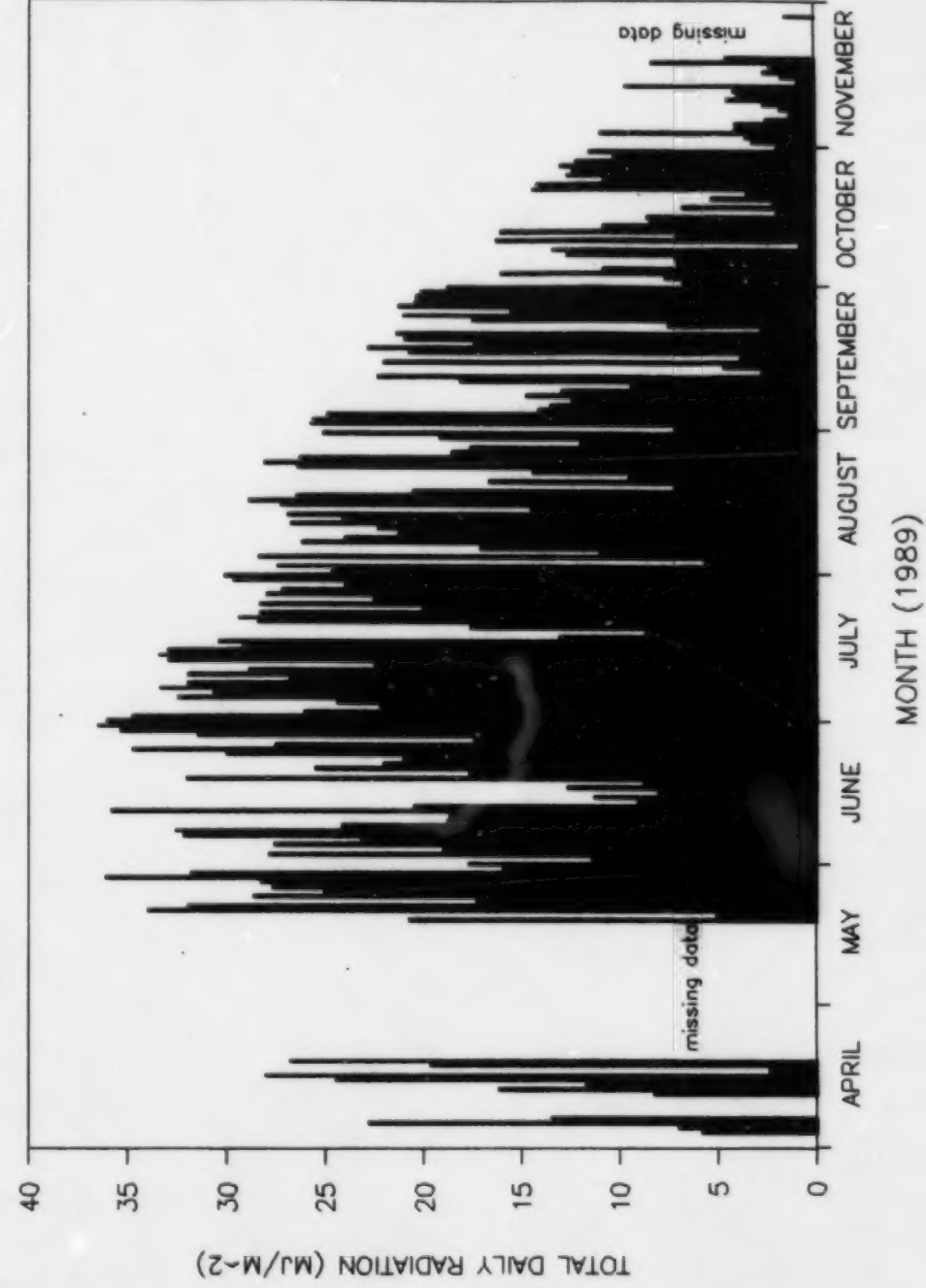


Figure 3.22: Daily Sunlight Radiation Levels in Study Watershed



was not generated. Dry soil conditions were also present for the relatively large rain which occurred in early September. Higher antecedent moisture conditions were present for the large storm which occurred in October. This storm also coincided with the planting of winter wheat in the watershed. When field observations were made during this event, it appeared that the loose, freshly tilled soil decreased runoff from this high volume yet relatively low intensity storm. The field visit during this storm observed a small amount of ponding just beginning to develop immediately around the inlet. It did not, however, reach the level of the inlet's intake holes.

Flow was detected during the November 15, 1989 runoff event. Even here, however, data were limited due to two key failures in the monitoring system. The first failure centred around the pressure transducer. Air temperatures a few days prior to the November 15, 1989, runoff event went below freezing. As a result, the pressure transducer was subjected to the adverse affects of frozen water in the stilling well. It is strongly suspected that it was during this period that the pressure transducer was damaged for it did not provide water level readings for the pond during the runoff event. Damage as a result of moisture around the pressure transducer's end cap is another possibility. Without water level readings in the pond, the flowrates exiting the terrace were not determined until they exceeded 4 L/s (i.e. when the flowmeter was programmed to measure flowrates). Only then did water sampling begin to occur. Flowrates continued to be measured until they were less than 4 L/s.

A second error in the monitoring system was also encountered. The water quality sampler took only two 500 ml samples (i.e. filled one bottle) and then stopped. The reason for this was an error in programming the water quality sampler itself. It was programmed to make one composite sample rather than undertake sequential composite sampling. As a consequence only one water sample taken near the peak of the storm was available for analysis. A detailed presentation of the data that were gathered from the November 15 storm event follows.

3.5 Analysis of the Data Collected From the November 15 Runoff Event

3.5.1 Water Quantity Data Analysis

On initial inspection it appeared that little information could be gleaned from the limited supply of data available for this single runoff event given the equipment and operational failures which occurred. On closer inspection however, it was revealed that sufficient data were available to quite accurately construct the data set as it would have been gathered by the datalogger if all components had been operational.

Data construction began with a detailed analysis of the information which was available. First, a closer look was taken at the amount of rainfall which occurred during the month of November (see Figure 3.23). The local study team member visited the site at or near the peak period of all the larger storms and observed no ponding around the inlet on all but the November 15 storm. For this storm, he visited the site between 4:15 and 4:30 p.m. At this time, he noted ponding and that water was passing through the Hickenbottom inlet. If a more detailed rainfall intensity graph is plotted for November 15, 1989, the exact rainfall event which triggered this ponding which was observed in the field can be pinpointed (see Figure 3.24). It would appear to be the rain event which started at 3:54 p.m. and continued through until 6:30 p.m. An even more detailed account of the timing and intensity of this specific storm is shown in Figure 3.28 later in this section. Thus, the exact storm triggering the runoff event is known.

To develop a more complete picture of the event, a few assumptions need to be made. The first assumption is that the pond was empty at 3:54 p.m. The second is that the runoff water began arriving within the next 6 minutes. Both assumptions seem reasonable given the low level of rainfall intensity in the few hours prior to 4:00 p.m. and that the theoretical time of concentration estimate for the watershed is approximately 5 minutes.

A detailed representation of the pond's ground contours was required to estimate pond volumes. Such information was available from the re-installation of the sediment cups on a 3.3 m (10') x 3.3 m (10') grid pattern. This detailed contour map is presented in Figure 3.25 and was used to initially determine the volume of water which was required to fill the dead storage in the pond. As can be seen from Figure 3.25, there are two dead storage zones - one around the closed inlet and one around the monitored inlet. Contour stage-storage calculations reveal that the dead storage available around the closed inlet was 4440 L. The dead storage surrounding the monitored inlet was 196 L. Figure 3.26 and 3.27 show site conditions and the condition of the sediment cups within the ponding area 15 hours after the runoff event.

Further information can be gained by reviewing timing and flow volumes recorded by the micrologger from the flowmeter when the logger sent a pulse to the water quality sampler. The micrologger was programmed to send a pulse to the water quality sampler every time 100 L of water passed through the pipe. Thus, a total of 20 pulses would be sent to the sampler, before a sample was taken. Knowing this, the data stored following each pulse sent to the sampler were blocked into groups of twenty. Five complete blocks of twenty were formed from the data. The flow volumes stored for each block were added and this total was then divided by the total time which elapsed between the time of the pulse sent from the preceding block of twenty pulses and the twentieth pulse in the block concerned. This gave an average flowrate for each block of twenty pulses, or, in other words, the average flowrate over a period

Figure 3.23: Daily Rainfall in Study Watershed for the Month of November 1989

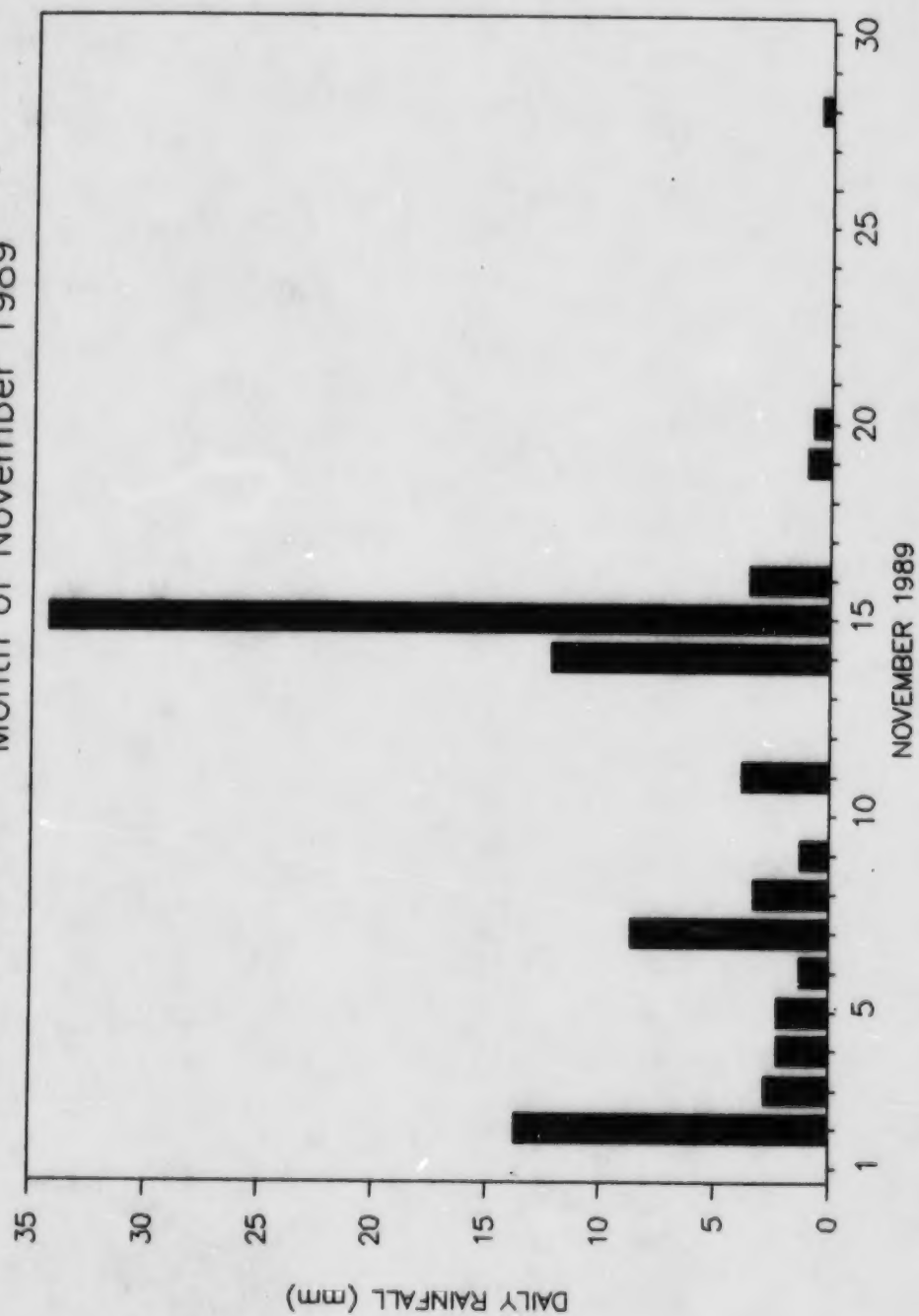
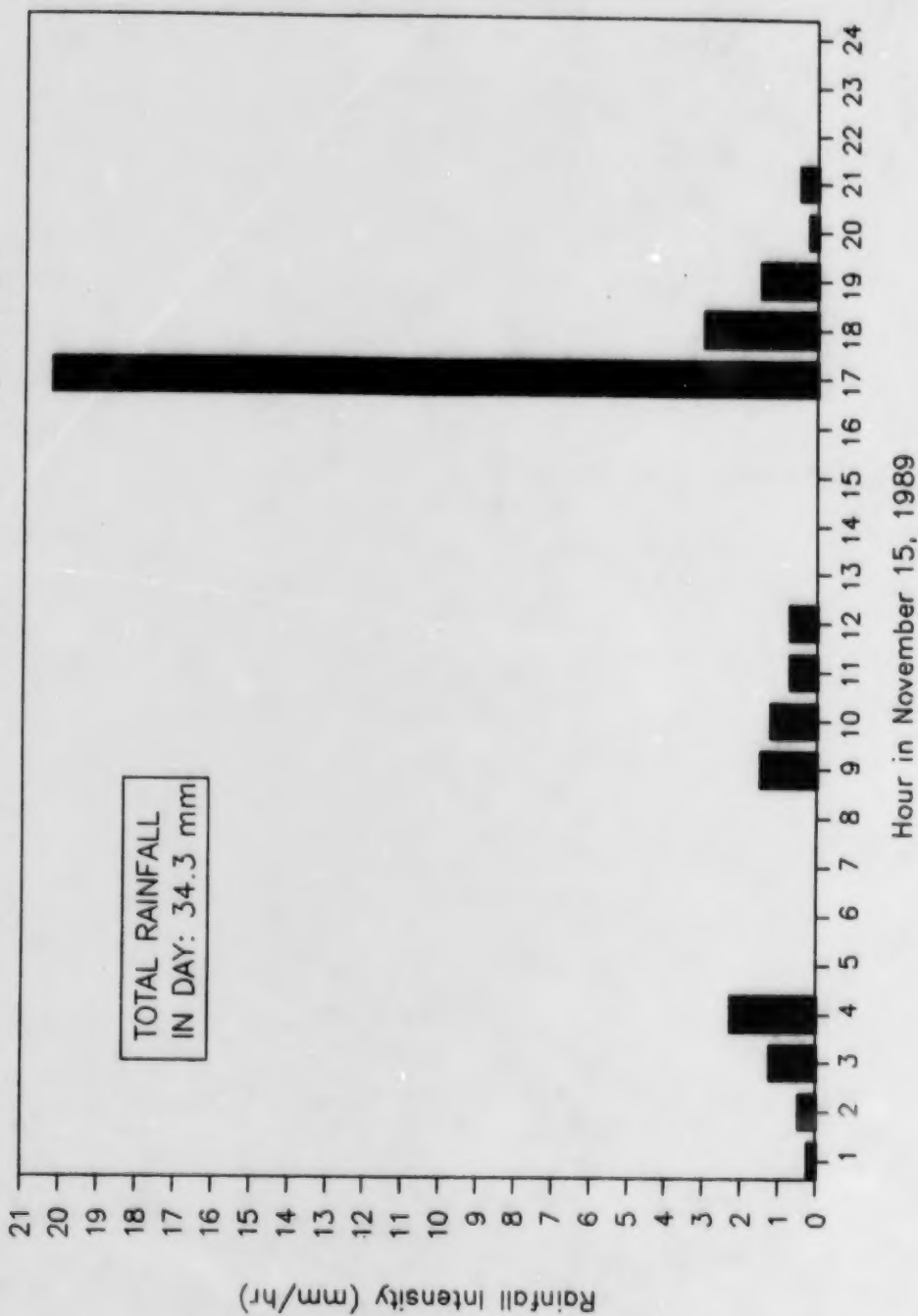
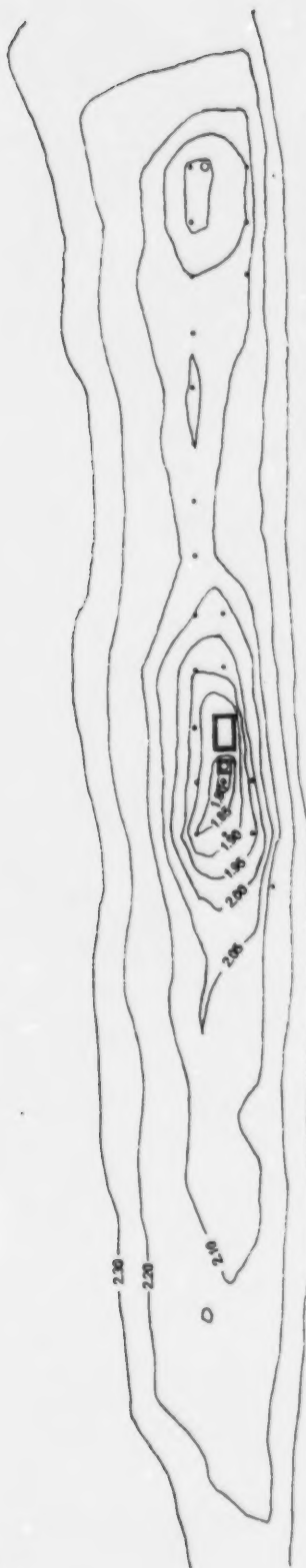


Figure 3.24: Hourly Rainfall Intensities
on November 15, 1989





NOTES

1. CONTOUR INTERVAL VALUES AS MARKED ARE NOT RELATIVE TO ORIGINAL BENCHMARK (SEE FIGURE 3.3).
2. ADDITIONAL SEDIMENT CLIPS WERE PLACED IN THE IMMEDIATE VICINITY OF THE CATCH BASIN.

LEGEND

- SAMPLED SEDIMENT CLIP LOCATION
- CLOSED INLET
-  MONITORING CATCH BASIN
- ◻ STILLING WELL
(MONITORED INLET 1m WEST OF WELL)



SCALE: 1:275



DRY WEIGHT OF SEDIMENT COLLECTED IN CORRESPONDING SAMPLED SEDIMENT CUP ABOVE (grams)												
2.13	0	0.26	0.17	0.29	0	0	9.39	10.15	9.97	10.11	13.04	15.72
1.52	5.41		0.10	0.09								
2.13	0.28										0	9.76 9.83

CMS conservation
management systems
CONSULTANTS IN SOIL CONSERVATION AND WATER MANAGEMENT

Figure 3.25:

**Contour Map and Sediment Cup
Locations for the Ponding Area
NOVEMBER 15, 1969 (STORM)**



FIGURE 3.26: THE STUDY SITE IMMEDIATELY FOLLOWING THE RUNOFF EVENT



FIGURE 3.27: A SEDIMENT CUP WITHIN THE POND AREA AFTER AN EVENT

when a single 500 ml water quality sample would have been taken was determined. The results of these calculations are summarized in Table 3.7.

Table 3.7: Average Pond Outflow Rates During Peak Outflow Period
(November 15, 1989)

Time Period (hrs:min:sec)	Average Flowrate per Period (litres/sec)	Number of Water Quality Samples Taken (i.e. 20 pulses = 1500 ml sample)	Number of Bottles Filled
16:19:36 - 16:22:45	23.1	1	0.5
16:22:46 - 16:28:55	8.9	1	1.0
16:28:56 - 16:33:25	12.2	1	1.5
16:33:26 - 16:36:45	27.3	1	2.0
16:36:46 - 16:57:35	4.4	1	2.5
16:57:36 - 16:58:35	17.2	(only 5 pulses sent)	-

The data presented in Table 3.7 enables formulation of the central or peak portion of the hydrograph. It also indicates when the single water quality sample bottle was filled (i.e. between 16:19:36 and 16:28:55 on November 15, 1989). A comparison between the timing and intensity of the rainstorm and the timing of the peak outflow rates, show good correlation providing confidence in the reconstruction of the outflow hydrograph to this point.

To reconstruct the remainder of the hydrograph, information available from the detailed contour map in Figure 3.25 was used. It can be assumed that the period of peak flow would correspond to the period of highest pond elevation. The position of the sediment cups collected which contained sediment indicated that the pond height never exceeded the 2.05 m elevation limit around the monitored inlet (ie: maximum pond depth at inlet 0.27 m). For the area around the closed inlet, the sediment cups indicated that the pond height never reached beyond an elevation of approximately 2.10 m. On initial inspection, such a situation may seem impossible. Note however that the water level around the closed inlet had to reach nearly this level before it could flow over to the monitored Hickenbottom side. Also note from the contour map of the watershed that the majority of runoff water would in all likelihood pass through the area surrounding the closed inlet before reaching the standpipe inlet. It was also noticed on the day following the event that water had formed a small rill between the closed inlet pond and the monitored

inlet pond indicating that such a flow pathway did exist. From this information, it was concluded that ponds of different heights could have easily existed if the high point between the two ponds had not been fully breached. If such were the case, it is also apparent that the Hickenbottom was discharging the runoff water at a rate matching or even exceeding the inflow from this adjacent pond.

Knowing the peak water levels surrounding the standpipe inlet, and the volume of water associated with each level, it is possible to calculate the outflow rates manually in a manner identical to that which would have been completed by the micrologger software, had the pressure transducer been working. Using the calibrated stage discharge equation and assuming the water level could be between 0 and 20 cm high on the Hickenbottom before discharge exceeded 4 L/s (see Figure 3.15), the recession limb of the hydrograph was constructed. A summary of these calculations is presented in Table 3.8.

TABLE 3.8: STORAGE AND CORRESPONDING OUTFLOW RATES USED TO CONSTRUCT THE HYDROGRAPH'S RECESSION LIMB (November 15, 1989)

Storage Volume (m ³)*	Water Depth on Hickenbottom (cm)	Average Outflow Rate (L/s)	Time to Drain (s)
3.66	15-20	3.61	1014s
2.20	10-15	1.73	1272s
1.25	5-10	0.55	2273s
0.565	0-5	0.07	8071s

* Volumes presented are around the monitored inlet only for it was assumed the adjacent sealed pond was not draining through the monitored inlet at these water depths. The contour map indicates that the adjacent pond contributed runoff to the outlet only during the peak outflow periods and that the Hickenbottom had the capacity to discharge the runoff water as quickly as it was being received.

The front side of the outflow hydrograph was somewhat more difficult to reconstruct. First, allowance had to be made to fill the dead storage in the pond (4640 L). If the assumption that the pond was empty when the rain event began at 15:54 is maintained and that runoff water began reaching the water at 16:00 (based on the time of concentration for the watershed), the pond had to be formed between 16:00 and 16:19:35 (i.e., when the flows exceeding 4 L/s were first detected by the flowmeter). From contour-stage-storage calculations and assuming that infiltration losses in the pond were minimal, the total volume of water required to fill the area around the inlet to an elevation of 2.05 m and which would also enable overtopping of the barrier between the monitored inlet and the sealed inlet is 12 315 L. The

only remaining volume of runoff or pond inflow water to be accounted for in this period of time is that portion which passed through the outlet between 16:00 and 16:19:35. To estimate this rate, it was assumed that the water level surrounding the monitored inlet rose at a rather constant rate. The weighted average flowrate based on this assumption was determined to be 2.33 L/s. Using this flowrate over a period of 9 minutes and 35 seconds, the total outflow through the pipe was estimated to be 1340 L. The entire outflow hydrograph could now be plotted and is presented in Figure 3.28. A pond inflow hydrograph was also constructed for the storm and is found in Figure 3.28 as well. It is based on many of the assumptions made above. The total runoff volume from the storm was determined to be 44,266 L (1,564 ft³) which translates into a water depth of 1.82 mm (0.072") over the entire watershed.

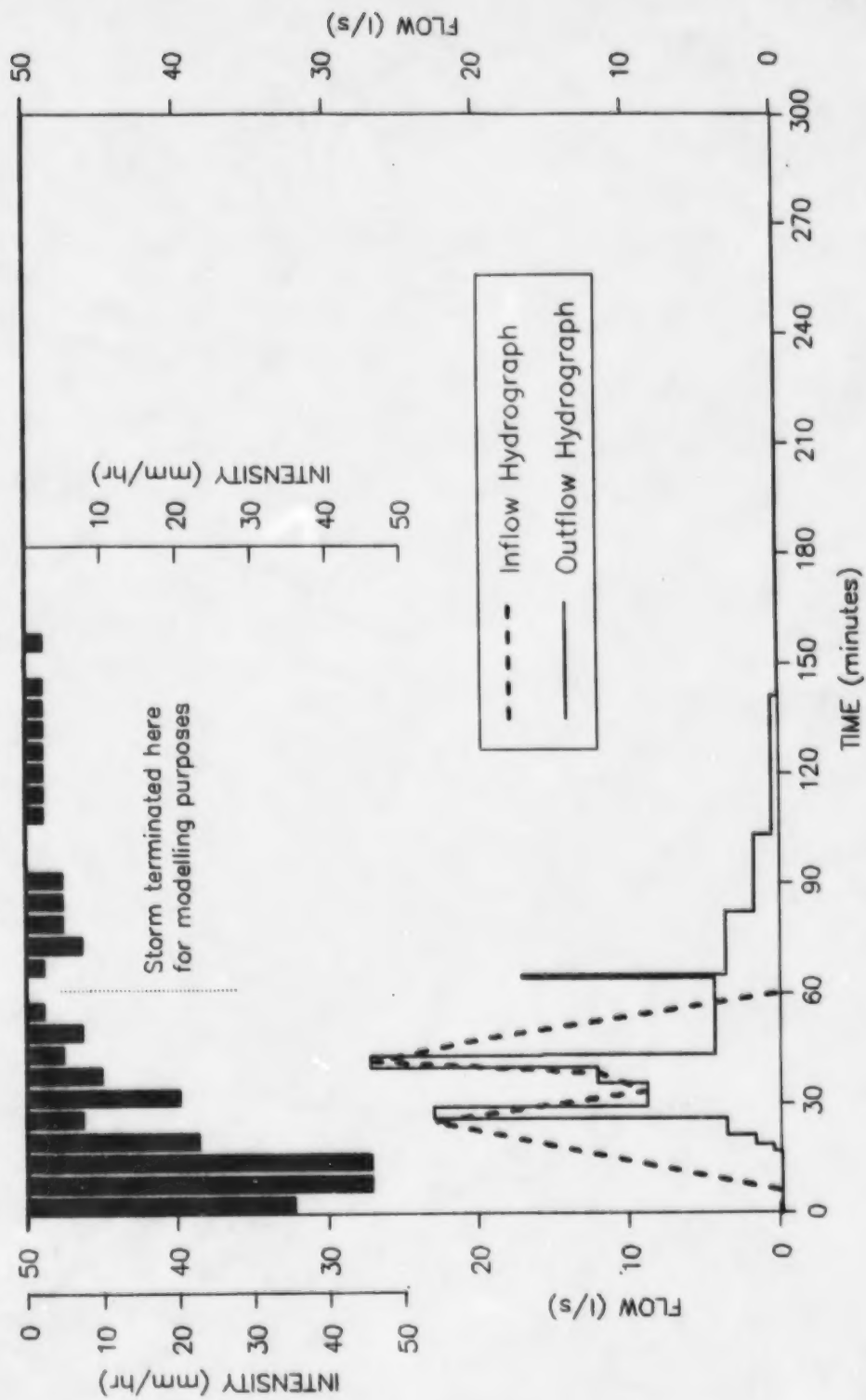
3.5.2 Water Quality Data Analysis

To determine the quality of the water entering and leaving the terrace, information was received from two sources. The first source was from the water samples taken from the outflow tile. If the system had been working properly and if the estimate made for total outflow is correct, theoretically there should have been 5 water sample bottles completely filled (i.e., 2 water samples/bottle, 11 samples taken). In actuality only one bottle was filled (i.e., 2 samples). The primary reason for this was human error, for the water quality sampler was inadvertently programmed to stop sampling after one bottle was filled. Even if the sampler had been programmed properly however, and if the pressure transducer was operating, fewer than 11 water samples would still have been taken. This is due to the fact that in many cases a pulse was not sent to the sampler until as much as 200 L of water passed by the flowmeter. This is nearly twice as much as the 100 L threshold the system was set for and was an inherent weakness in the data acquisition software developed. It is for this reason that Table 3.7 indicates that only 2.5 bottles would have been filled despite the fact that enough water passed to facilitate the filling of 5 bottles. This weakness in the data acquisition system could be easily overcome through software revisions by decreasing the number of pulses required to be sent for detection by the water quality sampler or conversely by increasing the threshold volume of water required before a pulse is sent by the datalogger to the water quality sampler. For example, if the system was set so one pulse was sent every time 1000 L passed, only two pulses would need to be detected by the sampler before a sample was taken. Alternatively the scanning frequency could be increased to facilitate the higher flowrates. Either way, the problems encountered here could be easily eliminated.

The following summarizes the laboratory results for the water sample collected:

pH Value	7.7
Suspended Solids	8940 mg/L
Total Phosphorus P	9.79 mg/L
Orthophosphate P	0.21 mg/L

Figure 3.28: Rainfall Intensity, Inflow and Outflow Hydrographs for November 15, 1989 Runoff Event



Two approaches can be taken in extrapolating this data to cover the entire runoff event. The first approach makes the assumption that the quality of the water passing through the tile remains relatively constant. Some justification for this assumption is possible given that the Hickenbottom appeared to be capable of draining the pond at a rate that matched the inflow rate, once the first 20 cm of storage depth was filled. Thus it was nearly a direct drainage situation and the terrace pond system was functioning more like a catchbasin/tile system than a temporary ponding system. The second approach would be to take the one observed value and the time the sample was taken and adjust it proportionally in accordance with the flows indicated by the outflow hydrograph. Both approaches were tried here.

The first approach is simple. If a total of 39,626 L passed through the tile system (i.e. total inflow minus dead storage) the total quantity of pollutants would be as follows:

Total Suspended Solids (sediment)	354 kg
Total Phosphorus P	0.39 kg
Total Orthophosphate P	8.32 g

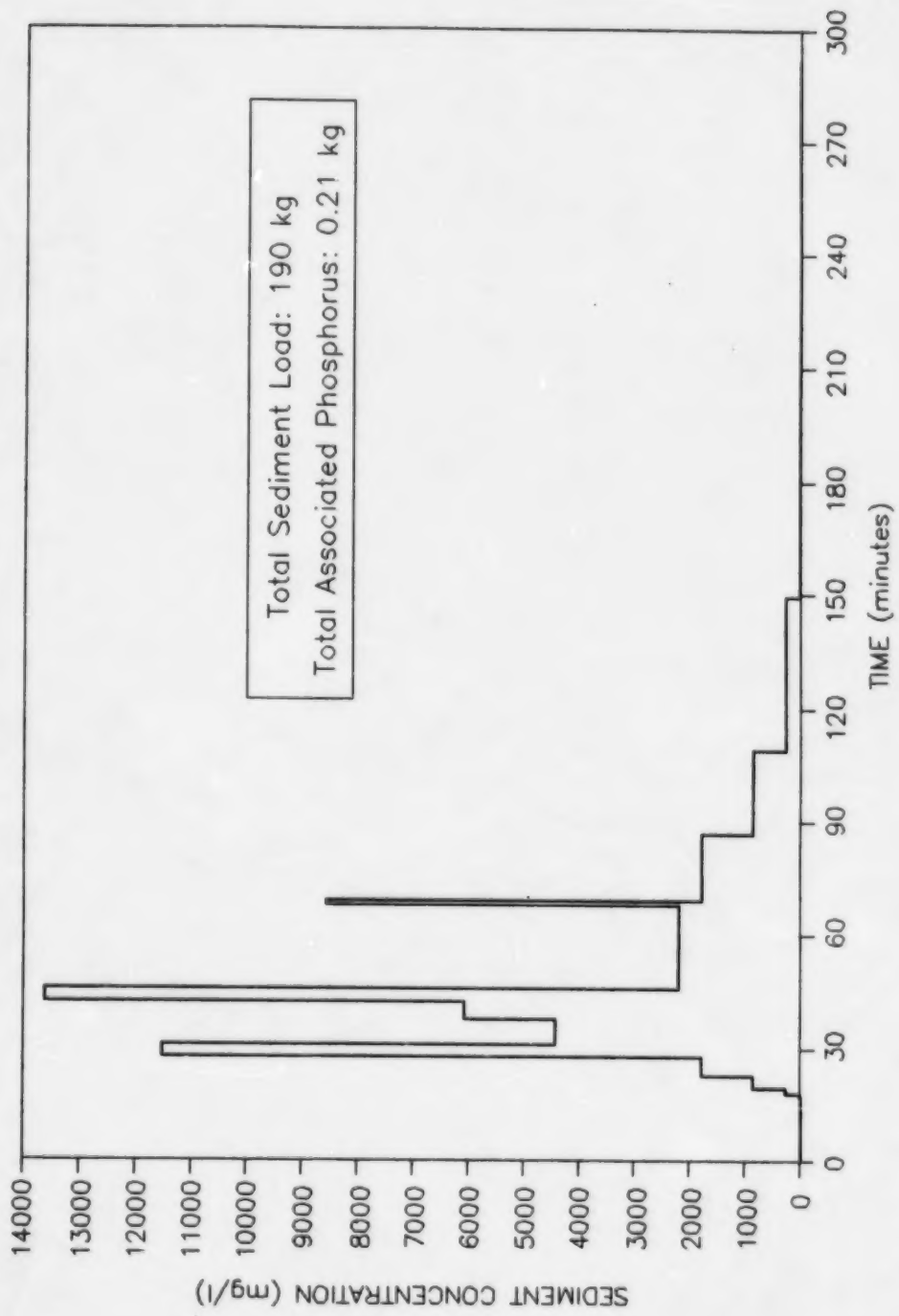
For the second approach, a sedimentgraph was constructed that followed the general shape of the outflow hydrograph. The resulting sedimentgraph is shown in Figure 3.29. Using this approach, the total quantity of pollutants is as follows:

Total Suspended Solids (sediment)	190 kg
Total Phosphorus P	0.21 kg
Total Orthophosphate P	4.47 g

Measurement of suspended sediment concentration during storm events has indicated that, while there is much variability in the differences in magnitude between the sediment load and the corresponding stream discharge, the two graphs do tend to follow a similar shape through runoff events. Data presented by D. E. Walling (1977) illustrates this. Results of computer simulation models such as HSPF and SEDCAD* which predict and graph sediment loadings, indicate that authors of the relationships embedded in these models have noted this general shape of a sedimentgraph as well. The output in Figures 3.30 to 3.33 (shown in Section 3.6.5.2) illustrate this point. The loading estimate which uses the outflow hydrograph as an indicator of the shape of the sedimentgraph would provide a more conservative and more realistic estimate than the first approach described.

To determine the quantity of sediment in the sediment cups analyzed (see Figure 3.25 for their locations), the weight of each direct sample was determined on an electronic scale with the difference between this total weight minus the sample bag minus the filter paper minus the nut taken as the weight

Figure 3.29: Sedimentgraph for November 15, 1989 Runoff Event



of sediment collected in the cup. Figure 3.25 also provides a table outlining the distribution of sediment among the cups sampled. The ratio of the total weight of all the sediment collected by the cups to the total surface area covered by the cups was multiplied by the maximum surface area inundated by water in the pond during the storm event. The result was a total dry weight of 50.3 kg of soil estimated to have been deposited in the pond.

To determine the amount of phosphorus trapped by the pond, a soil analysis was completed on a composite sample of sediment which was collected by the sediment cups. The results are as follows:

Total Phosphorus P	35.7 g
Total Available Phosphorus (NaHCO ₃ extractable)	0.7 g
Textural Analysis	silt loam (8.9% sand, 67.3% silt, 23.8% clay)

3.5.3 Results

With the above information, terrace efficiency for the November 15, 1989 storm was calculated to be 12.4 percent if the assumption that tile water quality remained relatively consistent throughout the runoff event and 20.9 percent on the assumption outflow water sediment content followed a "typical" sedimentgraph shape.

Similarly for phosphorus, the terrace was found to be between 9.2 percent and 17 percent efficient at removal for this particular storm event.

3.6 Computer Simulation of November 15, 1989 Runoff Event

Numerous mathematical models have been developed in the past and applied by means of computers to simulate erosion and sedimentation process on rural or agricultural land. The most common erosion model is the empirically based universal soil loss equation, commonly called the USLE. Other more physically-based models have also been developed. Both model types have been applied to estimate soil losses from watersheds. In these applications, the water erosion levels are closely related to the hydrology of the watershed. Accurate computer simulation of the watershed's hydrologic processes thus becomes a key component in the estimation of erosion losses. Similarly, a number of models have been developed to simulate the effect different erosion control measures have on erosion rates within a watershed. This section of the report describes the most suitable state-of-the-art models known to be available for simulating erosion and the effect of terraces on water quality in a watershed. The models were applied to the monitored watershed and the results compared with the field-measured values.

3.6.1 Background

A literature review was conducted initially to determine which models would be most suitable for modelling the monitored watershed along with the associated terrace system. The result was that four different erosion and sedimentation control models were selected for testing. Also, to ensure integrity in the modelling task, a hydrologic model was selected for application to the watershed. Its purpose was primarily to provide calibration parameters for the hydrologic components of the selected erosion models in order that differences detected could be attributed to the approaches the various models took in estimating erosion rates and terrace efficiency and not on their ability to estimate levels and rates of runoff. The hydrologic model along with the four erosion/terracing models selected are as follows:

- Hydrologic model (used for calibration):
HYMO - HYdrologic MOdel (Williams, Jimmy R. and Roy W. Hann, Jr., 1973)
- Erosion/Terracing models (used for simulation):
 - AGNPS: AGricultural Non-Point-Source pollution model (Young, Robert A. et al, 1987)
 - CREAMS: A field scale model for Chemicals, Runoff, and Erosion from Agricultural Management Systems (Knisel, Walter G. (ed.), 1980)
 - SEDCAD*: Sediment, Erosion, Discharge by Computer Aided Design (Schwab, Pamela J. and Richard C. Warner, 1988)

3.6.2 Application of HYMO

3.6.2.1 Model Description

HYMO, the hydrologic model selected to calibrate the other erosion models because of its commonly used approach to modelling runoff, was developed originally by the Agricultural Research Service branch of the United States Department of Agriculture in co-operation with the Texas A & M University. HYMO is a semi-distributed, deterministic, single-event, rural model designed to transform rainfall data into runoff hydrographs and then route these hydrographs through streams and valleys or reservoirs. It will also compute the amount of sediment produced by a storm over a watershed by means of the event-based modified universal soil loss equation (MUSLE). Rainfall data is transformed to storm hydrographs by convolving unit hydrographs with incremental source runoff. To compute the incremental runoff amounts, the mass rainfall is broken into equal time increments, and the Soil Conservation Service (SCS) rainfall-runoff relationship is applied. The SCS rainfall-runoff relationship is expressed as a set of numbered curves and is described fully in the SCS National Engineering Handbook. Determination of this parameter (the runoff curve number) was of prime importance for calibration of the other models

with respect to runoff levels. A digital copy of the input file listing the parameters used to describe the November 15, 1989 runoff event can be found in Appendix D.

The most difficult task in preparing the input data set was in determining the beginning and end of the particular storm event being modelled. One data set was prepared which used the same intensity histogram as that shown in Figure 3.28. Given that the bulk of the rainfall and the higher intensity levels fell within the first hour of this storm, the inflow hydrograph generated by HYMO declined rapidly soon after the first hour of the storm. In light of the input requirements of the sediment models and the results of the field data collected, it was decided to model the storm only for the first hour when 20 mm (0.8") of rain fell. The storm could be classified as being slightly less than a 2 year -1 hour storm event (see Section 3.2.3) although with numerous rain events preceding this storm, antecedent moisture levels were quite high, encouraging high runoff rates.

3.6.2.2 HYMO Output for the November 15, 1989 Event

Table 3.9 summarizes the HYMO output. Numerous runs were performed in order to determine the value for the runoff curve number which would generate the same amount of runoff for the storm as was measured in the field (i.e. 1.85 mm depth over the 2.43 ha watershed). This value was then used as a calibrated value for the other models where possible.

TABLE 3.9: SUMMARY OF HYMO OUTPUT FOR NOVEMBER 15, 1989 EVENT

Rainfall Amount (mm)	Rainfall Duration (hrs)	Runoff Curve Number (RCN)	Runoff Volume (mm over watershed)	Sediment Yield (kg)
20	1	85	1.85	909

Note that an estimate for the sediment yield was also calculated using MUSLE. This value was compared with results from the other models for interest.

3.6.3 Application of AGNPS

3.6.3.1 Model Description

AGNPS was developed in the mid-eighties by personnel with the North Central Soil Conservation Research Laboratory located in Morris Minnesota in response to the Minnesota Pollution Control Agency's need for a uniform method for evaluating agricultural watersheds in the state. The authors of AGNPS summarize their model as follows:

The objectives of the model are to obtain uniform and accurate estimates of runoff quality with primary emphasis on sediment and nutrients to compare the effects of various conservation alternatives for implementation as part of the management practices of the watershed and to develop a flexible and easy-to-use model. Analysis of pollutant loads from feedlots, investigation into the effects of implementing various conservation practices including impoundment terraces, and the ability to output water-quality characteristics at intermediate points throughout the watershed network are all within the model's capabilities. AGNPS is a single-event-based model intended to simulate sediment and nutrient transport primarily from agricultural watersheds in the State of Minnesota, although the principles on which the model is based are not limited to Minnesota. The model provides outputs on hydrology, with estimates of both volume and peak runoff, and on sediment, with estimates of upland erosion, channel erosion, and sediment yield. Along with these, the user receives estimates of the pollutants nitrogen (N), phosphorus (P), and chemical oxygen demand (COD), in units of concentration and mass, contained in the runoff and the sediment. The outputs can be examined for either a single cell or for the entire watershed. This information may then be used to rate the watershed objectively against other watersheds, to further pinpoint water-quality problems, and to investigate possible solutions to these problems.

Watersheds examined by the model must be segmented into square working areas called cells. This allows the model to provide water-quality information for specific locations within the analyzed watersheds. Groupings of the cells, determined by drainage pattern, make up numerous sub-watersheds. These sub-watersheds may be separately analyzed to provide further information on individual watershed sections.

The hydrology output of the model is largely governed by the selection of the appropriate runoff curve number for the watershed. Thus, the calibration results received in applying the HYMO model were applied here. Erosion rates in AGNPS are determined through application of the universal soil loss equation to each cell with the rainfall energy and intensity value input being the EI for the storm event under analysis. The methods used to predict nitrogen and phosphorus yields from the cells and watersheds are essentially identical to those used in the CREAMS model. For details on these subroutines, refer to either the AGNPS or CREAMS manual, both of which are available at no charge from their authors (see Appendix E).

To apply AGNPS the monitored study site was subdivided into three cells, two acres in size. (The program accepts only British units). An impoundment terrace was identified as being present at the outlet of the third cell. Parameters relating to each cell were then input. This input file can be found in digital form in Appendix D. For details concerning how the input data were determined, refer to an AGNPS User's Manual (Young, Robert A., 1987).

3.6.3.2 AGNPS Output for the November 15, 1989 Event

A general summary of the results generated by AGNPS can be found in Table 3.10. A detailed summary of the model's output for the November 15 storm event is found in digital form in Appendix D. In reviewing this data, it will be noted that the detailed summary indicates no runoff occurred for the storm. This value, however, is more likely to be a consequence of the number of decimal points allowed in the

formatting of the printed output data for other values in the model's printout indicate that runoff was indeed estimated.

Note that AGNPS does not calculate the terrace's efficiency directly. To obtain the efficiency estimates, the model was applied to two conditions. The first condition modelled the site with a terrace. The second condition modelled the site without an impoundment terrace. The differences in the results were used to calculate terrace efficiency. A detailed account of both runs is provided in Appendix D.

TABLE 3.10: SUMMARY OF AGNPS OUTPUT FOR NOVEMBER 15, 1989 EVENT

Runoff Volume (mm over watershed)	Total Estimated Erosion (kg)	Total Associated Phosphorus (kg)	<u>Pollutants Discharged through Outlet</u>		<u>Terrace Efficiency (%)</u>	
			Sediment (kg)	Phosphorus (kg)	Sediment	Phosphorus
1.85	2455	3.79	1182	1.55	13	10

3.6.4 Application of CREAMS

3.6.4.1 Model Description

The CREAMS model was developed by a task force formed by the United States Department of Agriculture's Agricultural Research Service. Its purpose is to simulate the effects of management systems on non-point source water pollution. It is one of the more widely used erosion models in the United States and in Ontario as well. Unlike AGNPS or SEDCAD^{*} it was designed to work at a field level rather than a watershed level. Also, CREAMS simulates on a continuous basis as well as on an event basis, and therefore is capable of including subroutines to calculate evapotranspiration along with soil evaporation. CREAMS is separated into three sub-models or components as follows:

- hydrology
- erosion/sediment yield
- chemicals (nutrients and pesticides)

Pass files from the preceding component are used along with the user-prepared input parameters to describe the watershed in a manner necessary for modelling.

The hydrologic component of the CREAMS model can be based on either the SCS curve number technique as with the other models described to date or the Green-Ampt infiltration model. Support data required for the more physically-based Green-Ampt method are more extensive including the need for parameters such as soil suction and soil saturated hydraulic conductivity. The set-up of the model however is such that, in order to use the runoff curve number, a continuous simulation of the site would need to be performed using daily rainfall data as storm input. Given the level of detail available for the November 15 storm and the fact that only one storm event needed to be simulated, it was decided that the alternate breakpoint model be used. This option requires time-intensity data for the storm(s) considered and uses the Green-Ampt model to estimate infiltration rates and thus runoff amounts. Calibration of the model so its runoff estimates would match the field-measured runoff volume from the watershed could be handled, by adjusting the parameters used by the Green-Ampt infiltration relationship.

Additional field data were needed for this alternate runoff estimate approach. The Guelph permeameter was used to measure the saturated hydraulic conductivity associated with the watershed soils. More detailed soil tests were also performed on samples to provide the required data. For data not collected, default parameter values were normally used.

The CREAMS model calculates soil detachment by both rainfall and runoff using modified forms of the USLE. The model determines the capacity of the flow to transport soil in three soil particle classes from the critical shear stress and fall velocity characteristics of the soil in these classes. Sediment is routed downstream with the flow. The transport capacity of the flow is used to determine if there is deposition of soil due to excess sediment generated from interrill detachment, or whether there is erosion because of a sediment deficit relative to transport capacity.

CREAMS predicts the amount of phosphorus transported by sediment by multiplying the soil phosphorus content by the amount of sediment generated by a runoff event and then multiplying this result by an enrichment ratio to compensate for the selective nature of the erosion and deposition processes. The relatively smaller fraction of phosphorus which is dissolved in the runoff water is also accounted for in CREAMS.

The relationships used to simulate the presence of an impoundment terrace were developed from regression analysis that fit relationships to output from a more complex model developed and validated by Lallen et al (1972) and Lallen et al (1978).¹ A much more detailed description of pond geometry is

¹ Note these are the same experiments conducted in Iowa described earlier in which sediment deposition was measured directly at grid intersection points in the pond.

required for CREAMS than with other models. The CREAMS manual describes all the model relationship quite thoroughly and is available from the authors at no charge. The input files created to represent the monitored site on November 15, 1989 can be found in Appendix D.

3.6.4.2 CREAMS Output for November 15, 1989 Event

The results of the CREAMS simulation for the November 15 runoff event are summarized in Table 3.11. Detailed output is provided on diskette in Appendix D. One particularly interesting result from the modelling centred around the value for the watershed's saturated hydrologic conductivity. Field measurements using the Guelph Permeameter showed K_{sat} to be 4.17 cm per hour. Using such a value, however, would not result in runoff from the watershed, except for very high intensity rainfall events. The saturated hydraulic conductivity value along with parameters which affected the antecedent soil moisture levels were altered in order to calibrate the model to generate the field-measured runoff amount for the November 15 storm. Calibration required a reduction of K_{sat} to 0.61 cm/hr. This value fell within the range recommended by the CREAM's user's manual for the soil type in the study area.

TABLE 3.11: SUMMARY OF CREAMS OUTPUT FOR NOVEMBER 15, 1989 EVENT

Runoff Volume (mm over watershed)	Total Estimated Erosion (kg)	Total Associated Phosphorus (kg)	<u>Pollutants Discharged through Outlet</u>		<u>Terrace Efficiency (%)</u>	
			Sediment (kg)	Phosphorus (kg)	Sediment	Phosphorus
1.85	48	0.175	38	0.14	21	20

A number of tests were performed using the CREAMS model to determine the sensitivity of the terrace impoundment component of the model. The primary variable considered was the outlet pipe's orifice co-efficient. The orifice co-efficient is determined in the model by an equation relating its value to the diameter of the outlet pipe. The orifice co-efficient is also related to the peak flow from the pond and corresponding maximum stage according to the following equation:

$$C_{or} = 3600 Q_p / y_d^{0.5}$$

where: C_{or} is the orifice co-efficient

Q_p is the peak discharge (ft^3/s)

y_d is the maximum pond depth (ft)

By entering the field-measured values for peak flow and maximum pond depth, the observed orifice co-efficient could be obtained. This value was 3558. The software estimated the orifice co-efficient to be only 1330. The tile diameter value was then adjusted to give an orifice co-efficient value of

approximately 3558. When this was done, the model, estimated the pond to be only about 0.8% efficient. Thus surcharging of the outlet tile does have an affect on the quality of water leaving the site.

3.6.5 Application of SEDCAD⁺

3.6.5.1 Model Description

The objective of the authors of the SEDCAD⁺ model was to integrate the engineering design of traditional and recent stormwater, erosion, and sediment control management techniques into one comprehensive system and thus assist in rapidly evaluating the effectiveness of alternative control options through application of computer aided design and engineering. The SEDCAD⁺ model has evolved through research efforts and computer program developments over the past decade at the University of Kentucky, Agricultural Engineering Department. Numerous Soil Conservation Service methodologies have been incorporated into the SEDCAD⁺ software.

In general terms SEDCAD⁺ is an event-based distributed parameter model. Runoff volume estimates are based on the runoff curve number approach like many of the previously described models. The option of employing two different erosion modelling techniques is possible for any application at hand. The one option is the modified universal soil loss equation relationship (MUSLE) which was also used by HYMO and AGNPS. The other alternative is a more physically-based approach call SLOSS. It calculates sediment yield for each distributed area using detachment and transport capacity theory. Detachment in interrill and rill areas are calculated in an identical fashion to that used in CREAMS. The sediment transport capacity is calculated from the Y-axis unit stream power equation (Schwab, Pamela J. and R.C. Warner, 1988).

Sediment pond efficiency modelling is based on concepts developed through research in the efficiency of sediment basins used to control the off-site effects of surface mining. Two sediment basin modelling algorithms are provided. The first model is called DEPOSITS (DEposits Performance Of Sediments In Trap Structures). It idealizes flow through a sediment basin by plug flow, or first-in, first-out flow, with no mixing between plugs. The detention time, fraction of inflow sediment and average water depth is calculated for each plug. The trap efficiency and effluent concentration is determined from the amount of sediment that would settle from each of four horizontal layers. Stoke's law is used to calculate settling velocity.

The second sediment basin model is called CSTRS (Continuous Stirred Type Reactors). It issues a series of two continuous stirred reactors to evaluate the pond performance. With the CSTRS model, inflow sediment concentrations mix with sediment concentrations from previous inflow slugs.

Experimental work completed by authors of SEDCAD* have shown CSTRS to be more representative of actual sediment basin performance. With both models, a detailed description of the sediment pond and type of outlet is required including stage-storage data, elevation of the principal outlet and elevation of the emergency spillway.

SEDCAD* does not model any nutrient loading or the trapping efficiency of sediment basins with respect to nutrients such as phosphorus. The addition of subroutines such as those used in CREAMS which utilize the enrichment ratio concept would need to be incorporated into SEDCAD* if the model was to directly calculate this information. Manual calculation of these values using SEDCAD* output is also possible and was undertaken for this study.

3.6.5.2 SEDCAD* Output for November 15, 1989 Event

Four different combinations of SEDCAD* subroutines were used to model the November 15, event and are as follows:

Erosion modelled by MUSLE, terrace modelled by DEPOSITS

Erosion modelled by MUSLE, terrace modelled by CSTRS

Erosion modelled by SLOSS, terrace modelled by DEPOSITS

Erosion modelled by SLOSS, terrace modelling by CSTRS

The resulting outflow hydrographs and sedimentgraphs are presented in Figure 3.30 to 3.33 inclusive. A summary of the results can be found in Table 3.12.

The runoff volume was just slightly higher than that calculated by the other models despite the use of the calibrated runoff curve number. This can be attributed to the fact that the model only requests total rainfall depth and duration for the storm distributing the storm throughout that duration on the basis of a SCS Type II storm distribution. Phosphorus values found in Table 3.12 were estimated separately from the model on the basis of the CREAMS algorithms.

3.6.6 Summary of Modelling Results

The results of the modelling exercise were mixed. Of key importance was the calibration required to have the models give runoff volumes which matched the field-measured values. Simply entering the hydrology parameter values derived from site and literature inspection would have given a much wider range in results than is tabulated in summary Table 3.13. The ability of the reviewed model to determine the quantity of soil losses was also a factor as was the level of detail necessary for describing the terrace pond and outlet system itself.

Figure 3.30: SEDCAD⁺ Simulation Using MUSLE/DEPOSITS Models

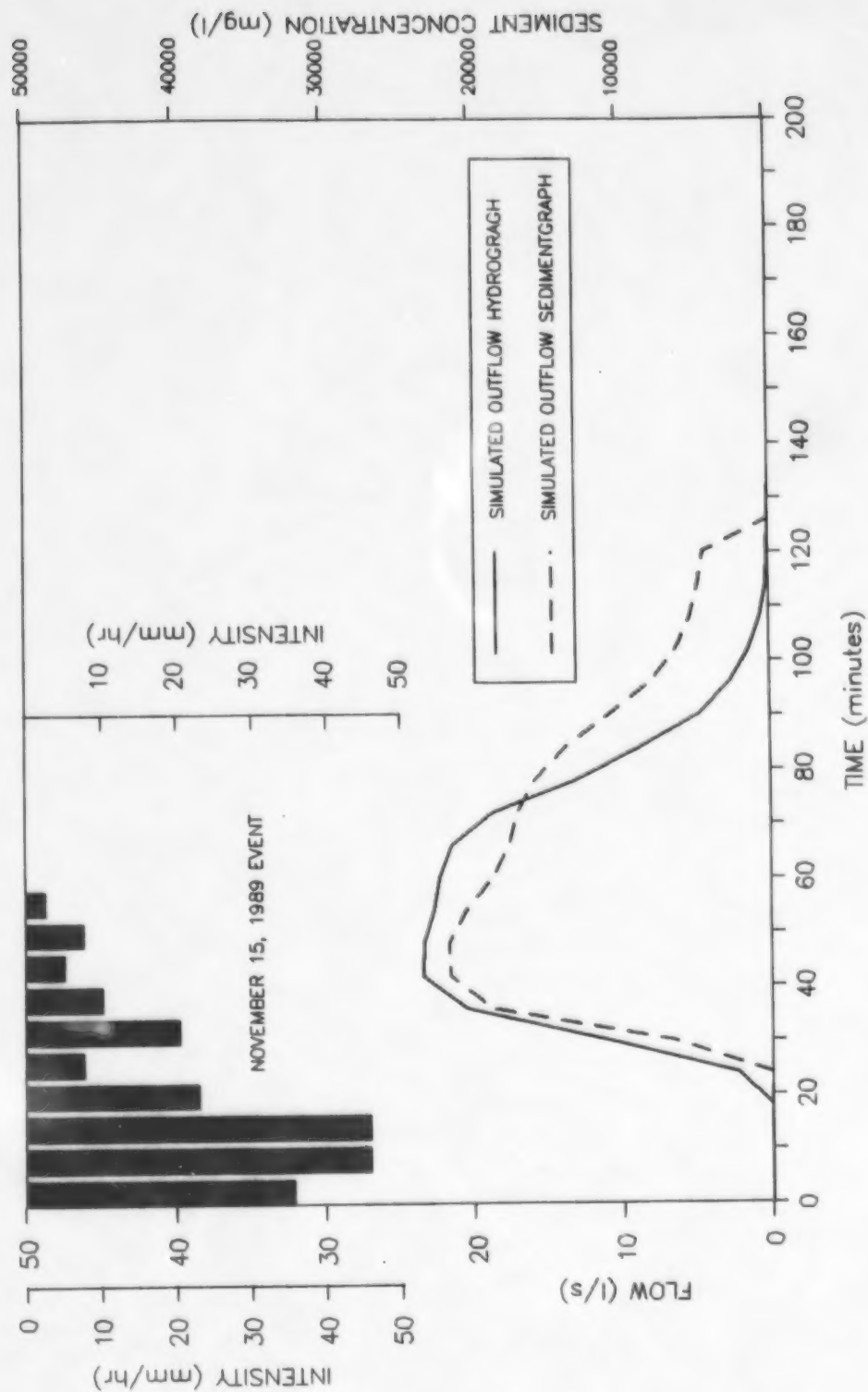


Figure 3.31: SEDCAD⁺ Simulation Using MUSLE/CSTRS Models

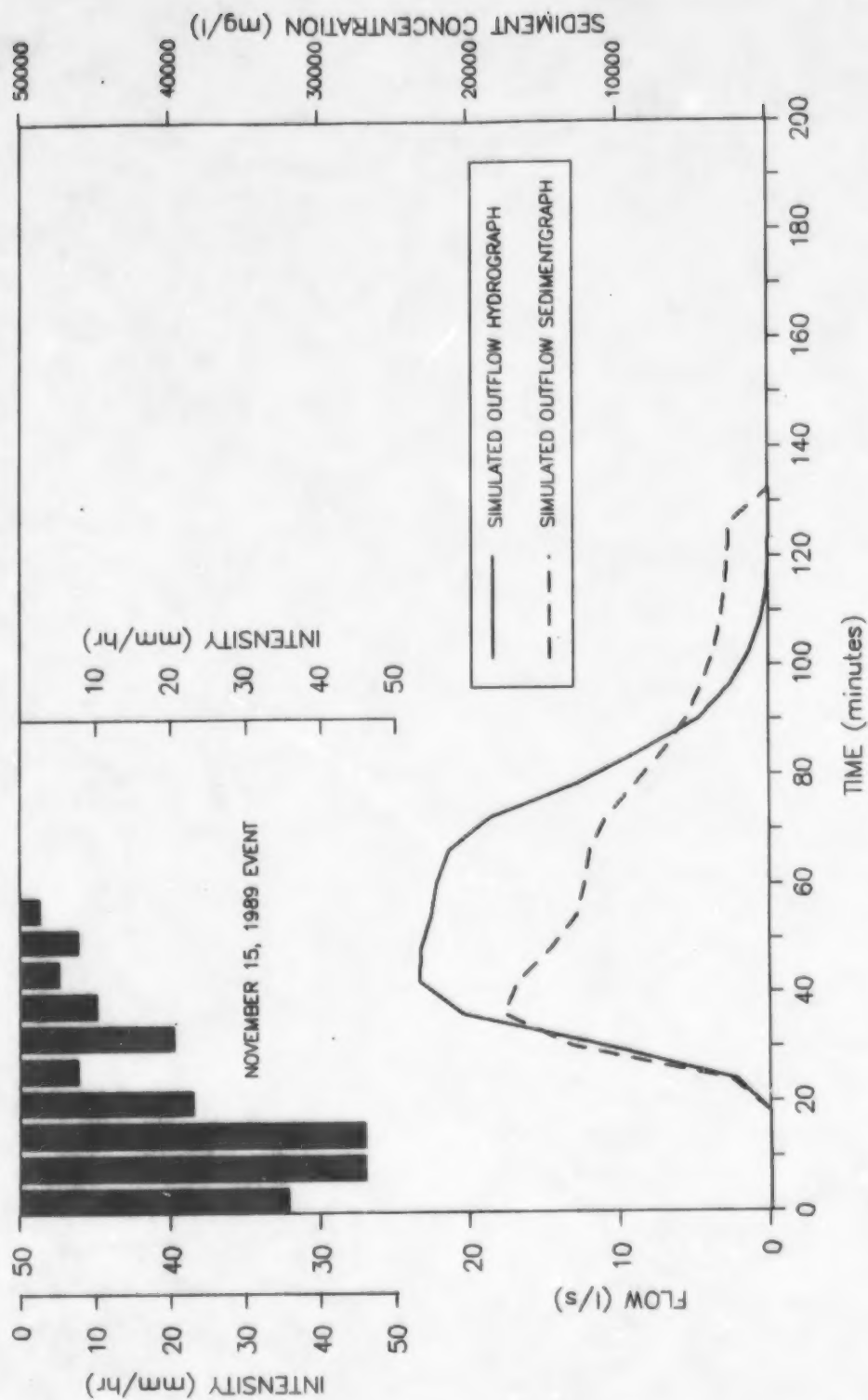


Figure 3.32: SEDCAD⁺ Simulation Using SLOSS/DEPOSITS Models

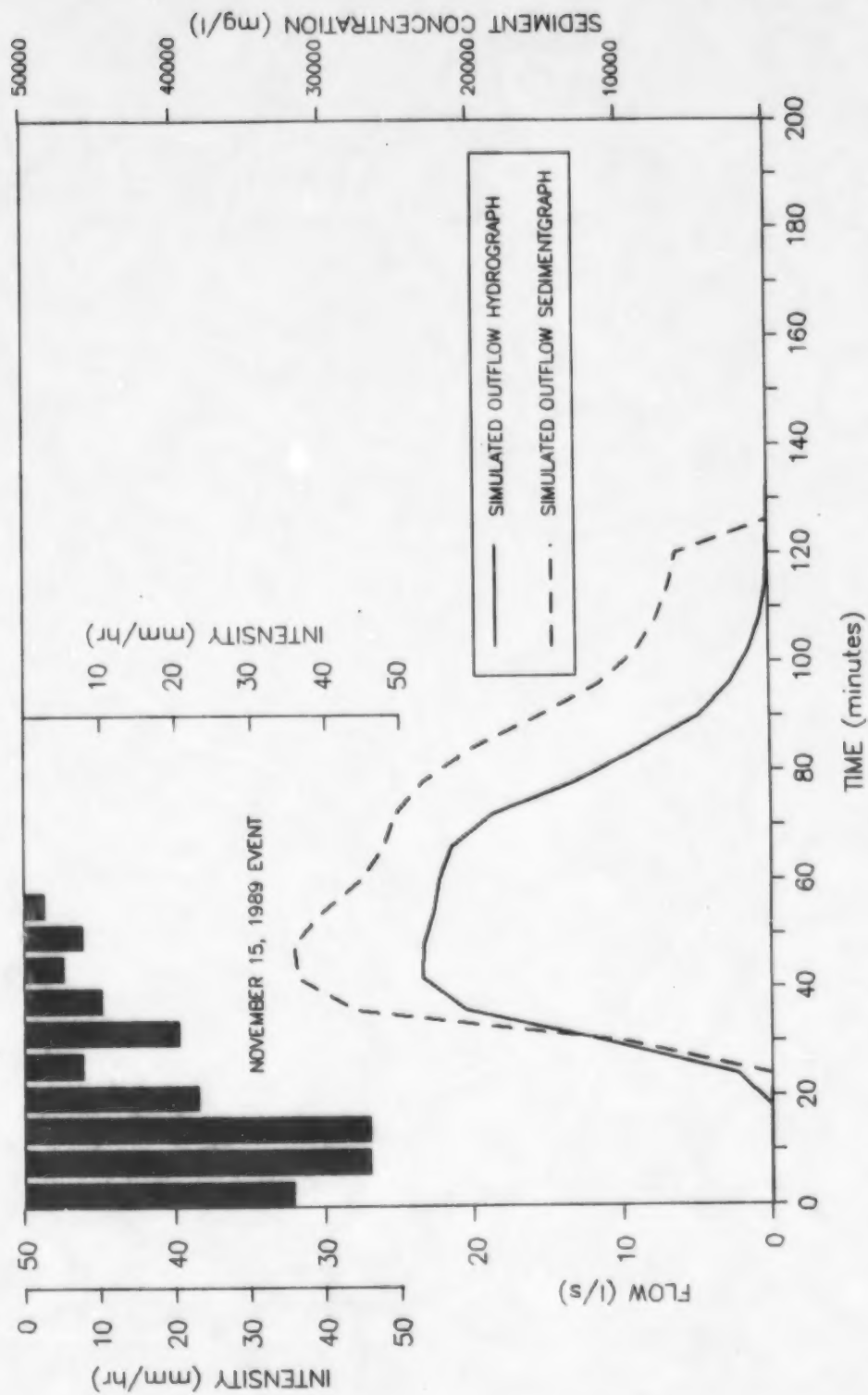


Figure 3.33: SEDCAD⁺ Simulation Using SLOSS/CSTRS Models

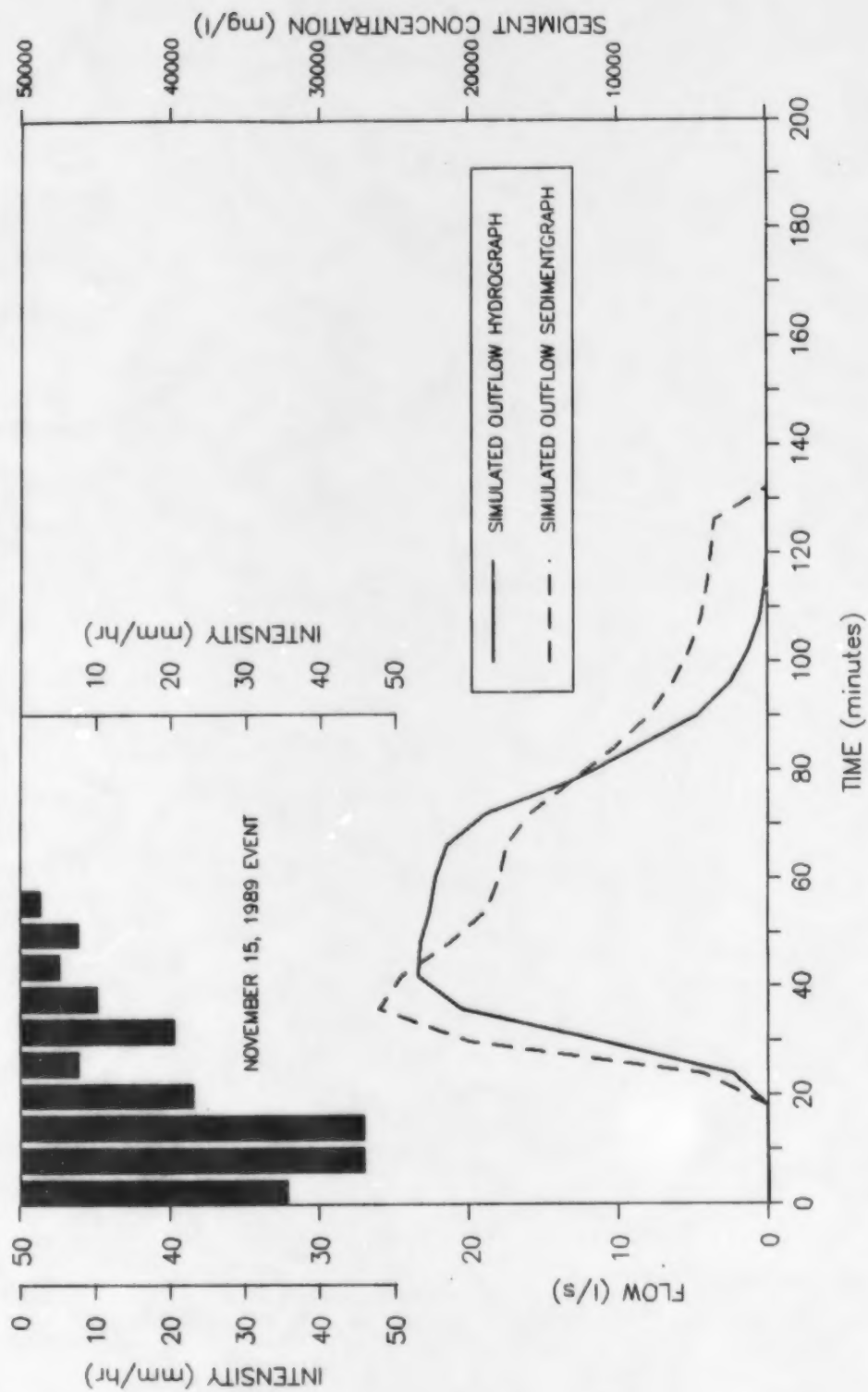


TABLE 3.12: SUMMARY OF SEDCAD⁺ OUTPUT FOR NOVEMBER 15, 1989 EVENT

Model Combination	Runoff Volume (mm over watershed)	Total Estimated Erosion (kg)	Total Associated Phosphorous* (kg)	Pollutants Discharged through Outlet Sediment (kg)	Phosphorus* (kg)	Terrace Efficiency % Soil	Phosphorus
MUSLE/DEPOSITS	2.29	1573	4.6	1009	3.36	36	27
MUSLE/CSTRS	2.29	1573	4.6	727	2.76	54	40
SLOSS/DEPOSITS	2.29	3427	10.1	1491	5.86	57	42
SLOSS/CSTRS	2.29	3427	10.1	1064	4.95	69	51

* Estimated values, not calculated by model.

Table 3.13: SUMMARY OF MODELLING RESULTS

Model	Runoff Volume (mm over watershed)	Total Erosion (kg)	Total Associated Phosphorus* (kg)	Pollutants Discharged through Sediment (kg)	Phosphorus* (kg)	Outlet Phosphorus* (kg)	Terrace Efficiency % Soil Phosphorus
HYMO	1.85	909	-	-	-	-	-
AGNPS	1.85	2455	3.77	1182	1.55	13	10
CREAMS	1.85	48	0.174	38	0.14	21	20
SEDCAD ⁺							
MUSLE/CSTRS	2.29	1573	4.6	1009	3.36	36	27
MUSLE/DEPOSITS	2.29	1573	4.6	727	2.76	54	40
SLOSS/DEPOSITS	2.29	3427	10.1	1491	5.86	56	42
SLOSS/CSTRS	2.29	3427	10.1	1064	4.95	69	51
FIELD MEASURED VALUES**	1.85 1.85	240.3 404.3	-* -*	190 354	0.21 0.39	20.9 12.4	9.2 17

* Note estimates made by multiplying the laboratory value of 629 mg/kg for total phosphorus in the top 1 inch soil layer gave values less than the total phosphorus attached to the discharged sediment.

** Two sets of field measured values were given representing the two different approaches used to extrapolate available water quality data over the entire runoff event.

Evaluation of the Field Monitoring Apparatus

Laboratory testing of the field monitoring apparatus instilled confidence in the suitability of the field monitoring apparatus. Nevertheless, problems were still encountered once the system was installed in the field. Many problems present were more a function of human error and climatic conditions than a weakness in the apparatus itself and thus could be quickly overcome by experience. Having only one small event through the entire monitoring period severely limited the amount of experience gained in working with the apparatus. The one storm did point out the error made in programming the water quality sampler. It also pointed out a weakness in the portion of the developed software which totalled flow volumes for the purpose of triggering the taking of water samples.

Collection of sediment cup samples was found to be rather labour intensive although it was relatively simple. The labour and technique, however, were justified given the small sample of sediment collected for the event monitored. In the case outlined in this report, they also provided additional information needed on the pond's peak stage for the storm which normally would have been measured by the pressure transducer.

Freezing temperatures which resulted in the pressure transducer being submerged in ice two days prior to the runoff event, is thought to have damaged the pressure transducer. Overcoming this reality of Ontario climate conditions will be difficult although providing heat through a heat lamp or heating pad in the area of the pressure transducer is a possibility. The configuration of the flowmeter and water-sampling system is such that it is insulated from freezing temperatures. Even here, however, cold temperatures adversely affect the longevity of nicad battery power packs needed to operate the equipment. Frequent battery replacement is critical during cold weather. Such problems will only be experienced during the spring runoff or late fall periods. It is this period in Ontario, however, when much of the erosion is perceived to occur. Verifying this hypothesis will be difficult. For spring and summer situations, with human error eliminated, the developed monitoring system is expected to work well.

Reviewing the sediment loading data for the water sample taken, it can be seen that the concentration of suspended solids was coming dangerously close to the upper limit allowed by the manufacturer for the proper operation of the flowmeter. This perhaps forewarns a need to select an alternate type of flowmeter, such as a magnetic flowmeter or vortex meter, which can accommodate higher sediment levels in the fluid flow being monitored.

Evaluation of Terraces as a Technique to Reduce Phosphorus Loadings to Watercourses

With only one field-measured event available from this study, conclusions as to the overall effectiveness of terrace structures in reducing sediment and phosphorus loads to open streams is impossible. For this event, which produced an amount of rainfall equivalent to 80% of that associated with a 1 hour duration, 2 year return period storm, the terrace's efficiency was relatively low at 10 to 15 percent. A comparison of the peaks on the inflow and outflow hydrographs however, (see Figure 3.28) points out the fact that the system was acting more like a tile/catchbasin system than a terrace system. Thus conclusions should not be drawn until data from runoff events which facilitate the normal operation of a terrace system is gathered. It is expected that a channel terrace's effectiveness would increase in proportion to the erosivity of the runoff event.

Evaluation of Existing Modelling Techniques

In general, the SEDCAD⁺ software gave much more "favourable" results with respect to the basin's sediment trapping efficiency than any of the other models or even the field-measured values. The absence of a P loss algorithm in SEDCAD⁺ does not allow phosphorus loading comparisons to be made among the models. A major factor behind the more efficient sediment trapping results given by SEDCAD⁺ may be that the basin itself, for the runoff event monitored, was not operating like a detention pond system in the classical sense. Due to the relatively low volume of runoff, the outlet was able to discharge the runoff nearly as quickly as it entered and was in effect then acting more like a tile/catchbasin system. The models were being applied to a situation in which they were not really truly developed to model. This argument can be refuted, however, when reviewing the relative similarity between the AGNPS and CREAMS results to the field-measured data. Pond description data requirements were not as detailed for these two models.

Besides a suitable sediment pond modelling technique, it can be seen that of key importance are the supporting subroutines which estimate erosion rates on the watershed. Even with the hydrology component of the model calibrated, soil loss estimates varied considerably. This variation had an effect on the relative loading levels among the models but did not affect the efficiency of the pond for pond efficiency was driven by the calibrated runoff volume.

It is emphasized from the results of modelling that erosion control structures are most effective in controlling erosion generated by low frequency storm events. Sheet and rill erosion occurring during a typical rainfall event such as was encountered on November 15 (it being 80% of a two-year return period

storm) are still most efficiently and economically handled by a cropping and tillage program. It must be emphasized here, however, that this study did not consider the adverse downstream gulying effects that would have occurred if the runoff water was not diverted to the tile system, but instead continued to travel overland to the outlet. In such an analysis, channel terracing would be much more beneficial. To date, however, the authors are not aware of any study which considers both aspects of a terrace system, except perhaps watershed type models such as SEDCAD*, which models ditch and gully erosion caused by overland flow. Comparisons of sediment loadings from a site to an open watercourse with and without a channel terrace at a certain location would provide more comprehensive evaluation of a sediment basin's total effect on receiving waters.

Recommended Changes to the Field Monitoring Apparatus

The following changes are recommended to improve future installations of the previously described apparatus:

- Install a rubber gasket between the sections of the catchbasin to prevent water seepage into the catchbasin at time of installation. For added insurance, mastic sealant material is also recommended to be installed on the portion of the catchbasin below the surface.
- Modify the existing data-acquisition software to more accurately totalize flow volumes. This can be easily accomplished by reducing the number of pulses sent to the flowmeter to trigger sampling.
- Install an economical analog water level recorder as a backup system for the pressure transducer in the event there is equipment failure or damage. Given the rarity of good sampling events due to the nature and purpose of sediment basins, it is critical that backup alternatives be available to obtain event data. It should be noted, however, that the water level recorder will not operate any more efficiently than a pressure transducer in sub-zero temperatures.
- If an AC power source can be supplied on site, replace the present flowmeter with a magnetic flowmeter to ensure proper operation when sediment concentration is high. Lower flowrates are also more readily detected by such a flowmeter. The apparatus configuration would not need to be altered. Cost of a magnetic flowmeter is not excessively more than the present type used. The same AC power source could also be used to power a heat source for protecting the pressure transducer and enabling its operation during critical spring and fall runoff events.
- Test the pressure transducer to evaluate its ability to compensate for temperature fluctuations as indicated in the manufacturers specifications.
- Field check all monitoring equipment during or immediately following periods of sub-zero temperatures.

The rule-of-thumb reduction in sediment reaching receiving waters as a consequence of terracing is sixty to eighty percent [USDA-SCS (Iowa), 1987]. The models all gave values which were either below or at the low end of this estimate for the storm event analyzed. Many of the models gave results which were quite close to the field-measured range of terrace efficiency. While comparison of one storm's incomplete field data with simulated data cannot provide confidence in a model's capability, it would appear from the estimations made that the terrace model subroutines do a reasonable job. The key, however, is in the accuracy of the associated hydrology and sedimentology routines. Both subroutines need to be calibrated in order to generate the proper amount of runoff. Calibrating the hydrology component is necessary to provide an accurate estimation of the carrying capacity available while the sedimentology component must be accurate for a good estimate of the magnitude of the loading.

The single runoff event measured and modelled in this study re-emphasizes the need for designers of such systems to be aware of the theory which is behind channel terracing systems. In order to filter out pollutants, channel terrace systems must be designed to optimize the ponding time to allow settling of sediment and yet avoid damage to the crop within the pond. Surface soil texture of the land being protected should also be considered when optimizing ponding time for a site. Orifice plates installed in the intake provide an economical means of reducing outflow rates from a pond. The problem will always exist for designers, however, in selecting the storm event which the pond is to accommodate. Compromises have to be made.

SELECTED REFERENCES

- Brasher, B.R., D.P. Franzmerler, V. Valassis and S.E. Davidson. 1966. Use of Saran Resin to Coat Natural Soil Clods for Bulk-Density and Water-Retention Measurements. *Soil Science*, 101:108.
- Knisel, Walter G., editor. 1980. CREAMS: A Field-Scale Model for Chemicals, Runoff and Erosion from Agricultural Management Systems. U.S. Department of Agriculture, Conservation Research Report No. 26, U.S. Government Printing Office. Washington, DC.
- Laffen, J.M, H.P. Johnson and R.O. Hartwig. 1978. Sedimentation Modelling of Impoundment Terraces. *Transactions of the ASAE St. Joseph, MI.* 21(6) 1131-1135.
- Laffen, J.M., H.P. Johnson and R.C. Reeve. 1972. Soil Loss from Tile-Outlet Terraces. *Journal of Soil and Water Conservation.* Vol. 27:74-77.
- Mielke, L.N. 1985. Performance of Water and Sediment Control Basins in Northeastern Nebraska. *Journal of Soil and Water Conservation.* Vol. 40:524-523.
- Omega. 1988. Flow and Level. Omega Engineering Inc. Stratford, CT.
- Schwab, Pamela J. and Richard C. Warner. 1988. SEDCAD* - Sediment, Erosion, Discharge by Computer Aided Design - User's Manual. Civil Software Design. Lexington, KY.
- Sheehan, D., and W.T. Dickinson. 1987. Hydraulic Capacity of Riser Inlets. *Proceedings of the Drainage Engineers Conference Ontario Ministry of Agriculture and Food.*
- Walling, D.E. 1977. Natural Sheet and Channel Erosion of Unconsolidated Source Material (Geomorphic Control, Magnitude and Frequency of Transfer Mechanisms in Proceedings of a Workshop on The Fluvial Transport of Sediment-Associated Nutrients and Contaminants. International Joint Commission's Research Advisory Board. On behalf of the Pollution from Land Use Activities Reference Group. Windsor.
- Williams, Jimmy R. and Roy W. Hann Jr. 1973. HYMO: Problem-Oriented Computer Language for Hydrologic Modelling - Users Manual. U.S. Department of Agriculture - Agricultural Research Service Research Report ARS-S-9, U.S. Government Printing Office. Washington, DC.
- Young, Robert A., Charles A. Onstad, David D. Bosch and Wayne P. Anderson. AGNPS. 1987. Agricultural Non-point Source Pollution Model. A Watershed Analysis Tool. U.S. Department of Agriculture, Conservation Research Report 35, 80p.
- USDA-SCS (Iowa). 1987. Protecting Your Soil. Soil Conservation District Workshop Training Manual. Des Moines, IA.

APPENDIX A

THEORY AND OPERATION OF OMEGA MODEL FP-5300 FLOWMETER

TURBINE FLOWMETERS

Flow Reference Section

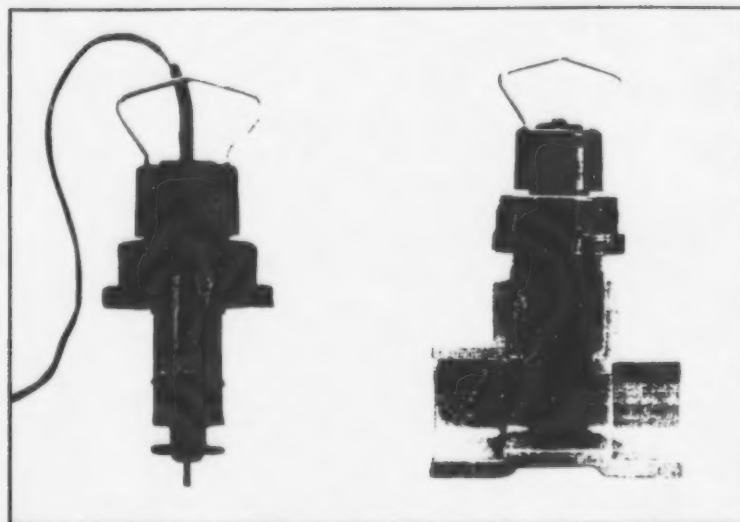


Figure 7: Paddlewheel flow sensor and installation fitting, which insures proper insertion depth into the pipe system

SPECIFYING FLOWMETER CALIBRATION

The standard calibration provided with all turbine flowmeters consists of a 10-point water calibration over the linear flow range of the meter. However, a number of optional flowmeter calibrations may also be requested.

Additional calibration points may be requested within the linear range of the flowmeter, at additional cost.

Calibrations of turbine meters for use with fluids having viscosities from 2 to 100 centistokes are performed with fluids of similar viscosities.

Universal viscosity calibration (UVC) curves may be documented for each individual turbine flowmeter where this information is required to achieve maximum flowmeter accuracy in medium to high viscosity service. In general, any flowmeter size may be supplied with the UVC curve, Fig. 1. However, since smaller meter sizes (under one inch) display the largest sensitivity of calibration factor to viscosity, it is this size range which

is the most likely to be considered for a universal viscosity calibration curve. The UVC curve may be utilized to determine the K-factor either graphically, or in the case of an intelligent instrument, algorithmically, for a measured set of flowing conditions.

A standard turbine flowmeter viscosity calibration consists of six repeated points for each viscosity required. A typical UVC curve requires three sets of six points plotted on graph paper as a continuous curve. In addition, a ten-point calibration and viscosity curve on a flowmeter at a single viscosity (up to 100 centistokes) is also available.

Viscosity Effects on Turbine Flowmeters

Turbine flowmeters may be used over a wide range of viscosity with the larger meters being viable over a wider viscosity range. For a given turbine flowmeter size and specified flow range, it is observed that as the viscosity increases, the lower portion of the flowmeter range is more affected than the higher portion of the range, Fig. 2. For a required accuracy of measurement, this results in a minimum linear flow rate increasing as the viscosity

increases. There is also a slight change in the average calibration constant, K , as the viscosity increases.

Selection for Viscous Service

In selecting a turbine flowmeter for operation in a viscous fluid, it is generally preferable to size the flowmeter so it will be operated in the higher portion of its range to minimize viscosity effects in the measurement. Due to the cost advantage of using an OMEGA® turbine flowmeter over competing flowmetering types, OMEGA® turbine flowmeters are often used at viscosities that introduce some loss in accuracy and some loss in flow range. Often, a turbine flowmeter may be considered as a candidate for an application with derated accuracy of $\pm 1\%$ of full scale, instead of the standard $\pm 0.5\%$ (or better) of reading accuracy.

In many viscous applications, the turbine flowmeter may be used since it remains repeatable under a given viscosity. Calibration at the operating viscosity may be used to determine the true viscosity dependency. Alternately, a turbine flowmeter may be used over wide viscosity ranges since the flowmeter has a unique, documented Universal

Viscosity Curve. These curves can be used to estimate the performance of a given line size on a specific fluid viscosity.

Through proper selection, consistent with other requirements of the application, the optimum flowmeter size may be chosen for a particular application.

FLOW STRAIGHTENERS, INSTALLATION KITS AND STRAINERS

Flow Straightening

Proper application of the turbine flowmeter requires a suitable piping section to achieve optimum accuracy. While an inlet straight pipe run of 10 pipe diameters and an outlet straight pipe run of 5 pipe diameters provide the necessary flow conditioning in general, some applications require an upstream flow straightener. Such applications include custody transfer. A flow straightener consists of a section of piping which contains a suitably dimensioned and position thin-walled tube cluster to eliminate fluid swirl, Fig. 8.

37° Flare Installation Kits

Installation kits for turbine meters with 37° flare end fittings consist of two lengths of stainless steel tubing cut to a length appropriate for the upstream and downstream straight pipe run and flared at one end. See page F-12. Mating sleeves and nuts are included. The kits may be conveniently butt-welded into the piping system. Flow straightening sections may be provided within the installation kit. These kits are available in tubing sizes from 1/2 to 2".

Strainers/Filters

A strainer/filter may be required to reduce the potential hazard of fouling or damage that may be caused by foreign matter.

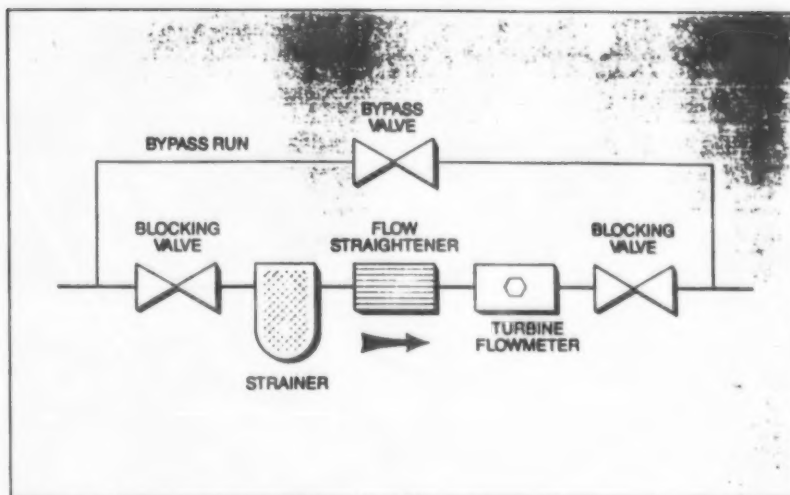


Figure 8: Typical turbine meter installation.

Recommended for the FTB-100 and 200 Series Turbine Meters are the following:

Meter Size	Mesh Size	Max. Particle Size
1/4 to 1/2"	100	0.0055
3/4 to 1 1/4"	70	0.008
1 1/2 to 3"	40	.015

PADDLEWHEEL FLOWMETERS

Paddlewheel flowmeters are very low cost substitutes for turbine flowmeters where the extremely high accuracy of the turbine is not required. In the case of the insertion-style paddlewheel sensors (FP-5000 Series), line sizes up to 8 inches can be accommodated at a much lower cost than competing in-line flowmeter systems. (See pages F-19 through F-26.)

In paddlewheel flowmeters, the rotor and blades are perpendicular to the flow, not parallel as with the turbine flowmeters, Fig. 9. Owing to the solid rotor design of these paddlewheel sensors, which includes no ball bearings, this type of flowmetering system is very tolerant of particulates in the line, and no strainers are required, as compared to turbine flowmeters. Because the

paddles contact only a limited cross section of the flow, the insertion depth of the rotor and proper flow profile are critical to accurate flowmeter performance. In the case of insertion-style paddlewheels (FP-5000 Series), installation fittings which have been specially modified to fix the insertion depth and direction of the rotor are sold separately. For the FPA and FPD Series Paddlewheel Meters, the tee fitting supplied with the complete system has also been specially modified to fix the insertion depth and direction of the rotor.

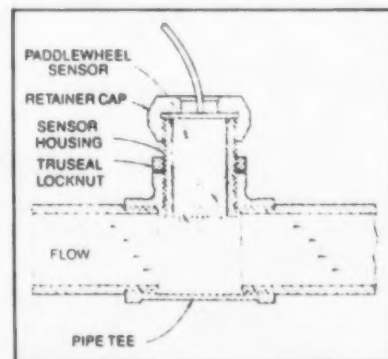


Figure 9: Paddlewheel flow sensor installation and operation

ACCURATE INDUSTRIAL FLOWMETER

Paddle Wheel Flow Sensors + Installation Fittings +



- For Liquids
- Low Pressure Drop
- Range: 1 to 50 FPS
- Inert to Most Acids and Bases
- $\pm 1\%$ Sensor Accuracy*
- Easy to Install and Maintain
- All Plastic Design Available

2 YEAR

WARRANTY

\$160

How To Order

- 1) Select Sensor per Pipe Size
- 2) Select Fittfor Pipe Diameter Page F-20
- 3) Electronics—See Pages F-27 through F-34

SENSORS

Model No.	Price	Accuracy*	Pipe Size
FP-5300	\$160	$\pm 1\%$ full scale	0.5" to 4.0" Diameter
FP-5301	190		6.0" to 8.0" Diameter

*All installation fittings are supplied with a plug for use when sensor is removed for repair or cleaning.

NOTE: For all plastic unit with PVDF rotor shaft, add suffix "AP" to sensor part number and add \$31 to base price.

SPECIFICATIONS:

Output Signal: Sine wave, 1 V p-p per ft./sec.

Output Frequency: 5-6 Hz per ft./sec.

Source Impedance: 8 K ohm

Range: 1-50 FPS

Linearity: $\pm 1\%$ full scale

Accuracy: $\pm 1\%$ full scale

Repeatability: $\pm 0.5\%$ full scale

Maximum Pressure: 200 PSIG max. at 68°F (20°C)

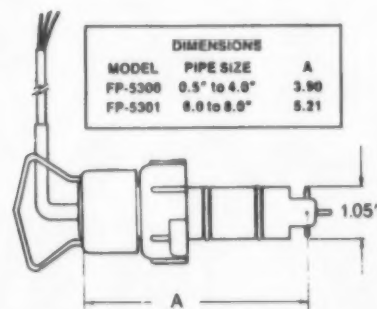
Maximum Temperature: PVC: 140°F max. @ 25 PSIG; CPVC: 180°F

Maximum Percentage of Solids: 1% of fluid volume

Pressure Drop: Equal to 8 ft. straight pipe.

Material: Transducer Housing: glass-filled polypropylene; O-Rings: Viton; Shaft: Titanium; PVDF opt. Rotor: PVDF
Cable Length: 25 ft., can be extended with copper wire to 200 ft.

The OMEGA® Series FP-5300 Flow Sensor is an electromechanical volumetric flow transducer which generates a sine-wave output with a frequency and amplitude linearly proportional to the rotor rotation velocity. Liquid flow rotates four permanent magnets past a coil, inducing an AC voltage proportional to this rotation rate. The frequency output is two cycles per rotation.



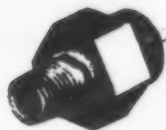
OMEGA's patented open-cell rotor design eliminates cavitation at flow rates up to 50 FPS for providing and maintaining superior linearity. Closed or solid rotor designs will cavitate at these velocities, creating a non-linear and non-repeatable signal.

The FP-5300 Flow Sensor is designed for operation in $\frac{1}{2}$ inch through 4 inches, where flow is fully developed. In 6 to 8 inch pipes, the FP-5301 should be used. These sensors can be used with fluids containing particulate matter up to 1% of volume.

APPENDIX B

SPECIFICATIONS OF SELECTED PRESSURE TRANSDUCER

230PC Series High Pressure Gage Sensors/Unamplified



FEATURES

- Male 1/8 NPT pressure port
- Remote atmospheric pressure reference
- Stainless steel housing

DESIGN CONSIDERATIONS

		Min.	Typ.	Max.
Excitation (VDC)	All 234PC	—	10	12
	All 236PC	—	10	16
(mA)	All 234PC	—	2.0	2.4
	All 236PC	—	2.0	2.4
Response Time (msec.)	All 234/236PC	—	—	1.0
Weight (grams)	All 234/236PC	—	56	—
Overpressure (see Accuracy specifications)				
Input Resistance (ohms)	All 234PC	—	5.0 K	—
	All 236PC	—	6.8 K	—
Output Resistance (ohms)	All 234PC	—	5.0 K	—
	All 236PC	—	4.0 K	—

ORDER GUIDE

PRESSURE RANGE

CATALOG LISTINGS*

Gage

ACCURACY SPECIFICATIONS

at 10.0 ± 0.01 VDC Excitation, 25°C

* Bold listings—Normally in stock.
Light listings—Check MICRO SWITCH distributor or Sales Office for availability.

Basic Sensor

Temperature Comp.

Parameter 230PC
Type

F.S.O.—Full Scale Output (mV) 234PC
236PC

Sensitivity per psi (mV) 234PC
236PC

Overpressure (psi) 234/236PC

Linearity

Best Fit Straight Line (%F.S.O.) 234PC
236PC

		Min.	Typ.	Max.
Null Offset (mV)	All 234PC	- 80	- 40	0
	All 236PC	- 2	0	+ 2
Null Shift (mV)				
25° to 0°C, 25° to 50°C	All 234/236PC	—	± 3.0	—
Sensitivity Shift (%F.S.O.)	At 10 VDC: All 234PC	—	± 6.5	—
	All 236PC	—	± 1.5	—
25° to 0°C, 25° to 50°C	At 2 mA: All 234PC	—	± 5.5	—
Repeatability & Hysteresis (%F.S.O.)				
	All 234/236PC	—	± 0.25	—
Stability over One Year (%F.S.O.)				
	All 234/236PC	—	± 0.5	—

ENVIRONMENTAL SPECIFICATIONS

Temperature	Operating	-30° to 70°C (-22° to 158°F)
	Storage	-40° to 105°C (-40° to 221°F)
	Compensated	0° to 50°C (32° to 122°F)
Shock	MIL-STD-202, Method 213 (100 g, half sine, 11 msec.)	
Vibration	MIL-STD-202, Method 204 (10 to 2000 Hz at 20 g)	
Media	P2 port Wetted materials: stainless steel 303 housing, epoxy adhesive, silicon, borosilicate glass, and silicon-to-glass bond*	

* Liquid media containing some highly ionic solutions could potentially neutralize the chip-to-glass tube bond.

Other Pressure
Sensors —
See Selection
Guide, pages 6 & 7.

0-5			0-15			0-30			0-60			0-100			0-150		
234PC05GW			234PC15GW			234PC30GW			234PC60GW			234PC100GW			234PC150GW		
236PC05GW			236PC15GW			236PC30GW			236PC60GW			236PC100GW			236PC150GW		
Min.	Typ.	Max.	Min.	Typ.	Max.	Min.	Typ.	Max.	Min.	Typ.	Max.	Min.	Typ.	Max.	Min.	Typ.	Max.
80	115	150	175	250	325	110	195	290	90	135	180	150	225	300	90	127.5	165
48	50	52	98	100	102	78	80	82	58	60	62	98	100	102	58	60	62
—	23.0	—	—	16.67	—	—	6.67	—	—	2.25	—	—	2.25	—	—	.85	—
—	10.0	—	—	6.67	—	—	3.33	—	—	1.00	—	—	1.00	—	—	.40	—
—	—	20	—	—	45	—	—	60	—	—	100	—	—	150	—	—	225
—	±1.5	—	—	±1.0	—	—	±0.50	—	—	±0.50	—	—	±.50	—	—	±.5	—
—	—	±3.0	—	—	±2.5	—	—	±1.5	—	—	±0.50	—	—	±0.50	—	—	±.5

234PC

No calibration
No temperature compensation
Lower price

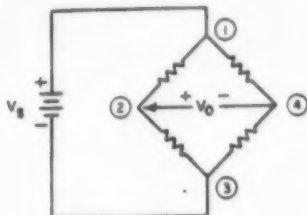
236PC

Calibrated Null and F.S.O.
Temperature compensated for F.S.O. over 0 to 50°C
Provides interchangeability

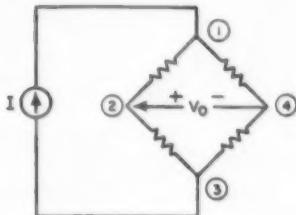
230PC Series High Pressure Gage Sensors/Unamplified

ELECTRICAL CONNECTIONS

Voltage Excitation 234/236PC



Current Excitation 234PC

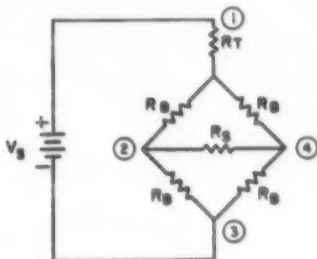


NOTES

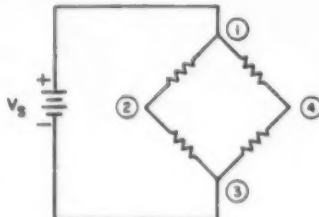
1. Circled numbers refer to sensor termination.
2. V_0 changes with pressure difference.
3. $V_0 = V_2 - V_4$ (referenced to pin 3).
4. Current excitation provides reduced sensitivity variation with temperature.

INTERNAL CIRCUITRY

236PC



234PC



NOTES

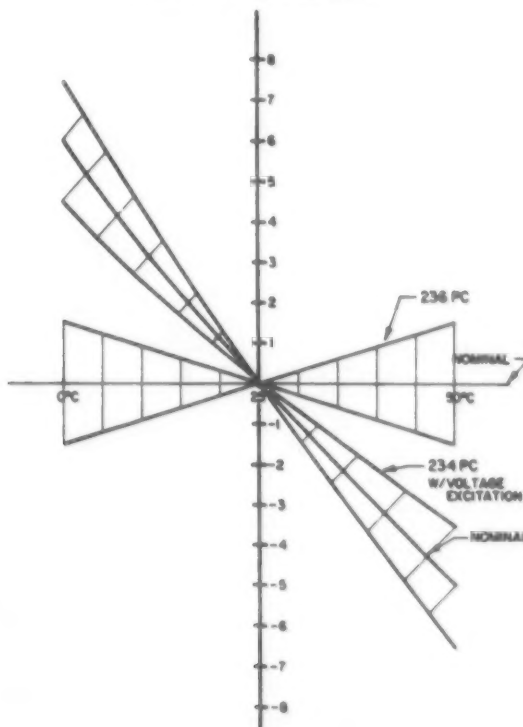
1. Circled numbers refer to sensor termination.
2. $V_0 = V_2 - V_4$ (referenced to pin 3).
3. R_S = Strain gage resistors ($\sim 4.8 \text{ k}\Omega$).
4. R_T = Sensitivity temperature compensation resistor.
5. R_S = Sensitivity calibration resistor.

When a positive pressure is applied to port P2, the differential voltage $V_2 - V_4$ (voltage at pin 2, with respect to ground, increases and voltage at pin 4 decreases) increases linearly with respect to the input pressure. When a vacuum pressure is pulled at port P2 (or positive pressure applied to port P1) the voltage $V_2 - V_4$ decreases linearly with respect to the input pressure.

SENSITIVITY SHIFT

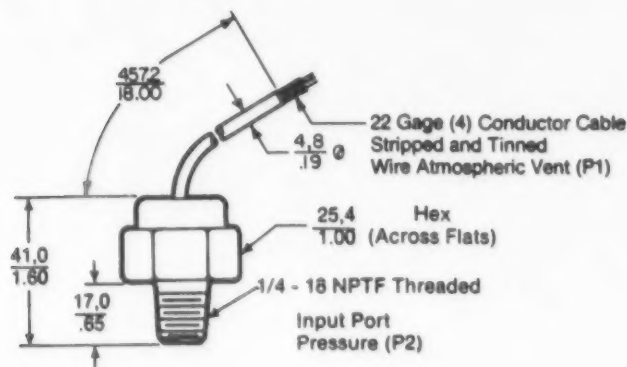
The diagram at right illustrates how sensitivity shift relates to temperature. Note that the maximum shift occurs at temperature extremes. Therefore, if a sensor is not exposed to the entire temperature range, the maximum sensitivity shift will actually be less than the value specified.

SENSITIVITY SHIFT (% F.S.O.)



High Pressure Gage Sensors/Unamplified 230PC Series

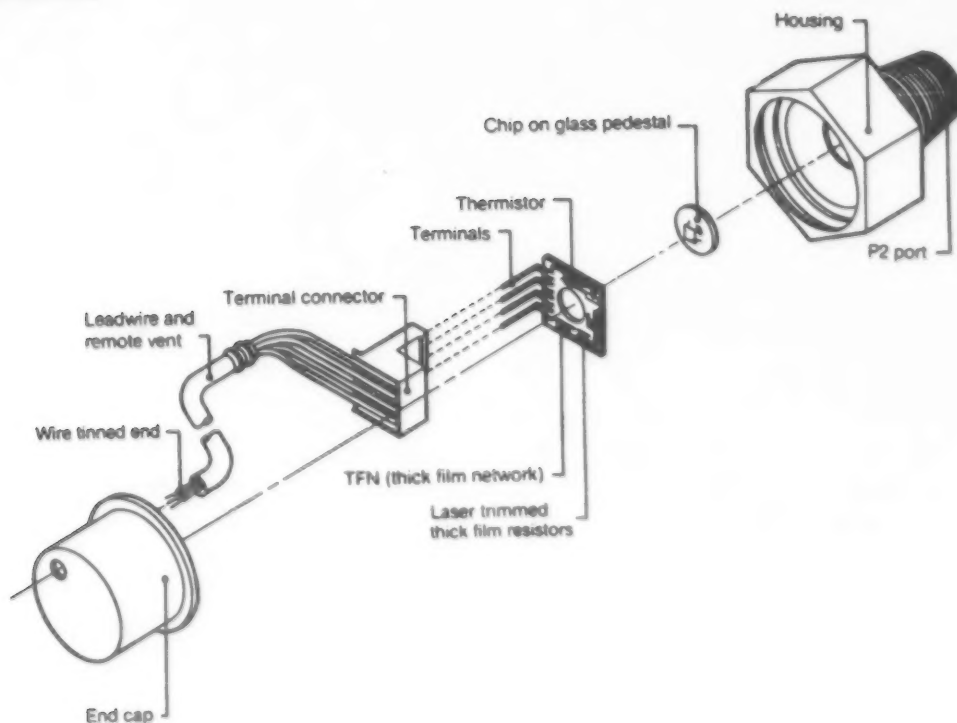
MOUNTING DIMENSIONS (For reference only)



Leadwires

- 1 - Red, Vs
- 2 - White, Output A
- 3 - Black, Ground (-)
- 4 - Green, Output B

230PC CONSTRUCTION



APPENDIX C

**THE DATA ACQUISITION SOFTWARE
(FOR CAMPBELL 21X MICROLOGGER)**

A P P E N D I X D

COMPUTER SIMULATION INPUT AND OUTPUT FILES (DISKETTE)

File Identification

<u>File Name</u>	<u>Description*</u>
HYMONU15.IN	HYMO INPUT
HYMONU15.OUT	HYMO OUTPUT
AGNPSN15.IN	AGNPS INPUT (impoundment terrace modelled)
AGNPSN15.OUT	AGNPS OUTPUT (impoundment terrace modelled)
AGNV15NI.IN	AGNPS INPUT (no impoundment terrace)
AGNV15NI.OUT	AGNPS OUTPUT (no impoundment terrace)
CRAINV15.DAT	CREAMS BREAKPOINT RAINFALL DATA
CRHYDN15.IN	CREAMS HYDROLOGY INPUT
CRHYDN15.OUT	CREAMS HYDROLOGY OUTPUT
CRHYDN15.PAS	CREAMS HYDROLOGY PASS FILE
CRERON15.IN	CREAMS EROSION INPUT
CRERON15.OUT	CREAMS EROSION OUTPUT
CREON15.PAS	CREAMS EROSION PASS FILE
CRNUTN15.IN	CREAMS NUTRIENT INPUT
CRNUT15.OUT	CREAMS NUTRIENT OUTPUT
CRNUTN15.PAS	CREAMS NUTRIENT PASS FILE
SCNV15MC.INP	SEDCAD* INPUT (MUSLE and CSTRS used)
SCNV15MD.INP	SEDCAD* INPUT (MUSLE and DEPOSITS used)
SCNV15SC.INP	SEDCAD* INPUT (SLOSS and CSTRS used)
SCNV15SD.INP	SEDCAD* INPUT (SLOSS and DEPOSITS used)
SCNV15MC.OUT	SEDCAD* OUTPUT (MUSCLE and CSTRS used)
SCNV15MD.OUT	SEDCAD* OUTPUT (MUSCLE and DEPOSITS used)
SCNV15SC.OUT	SEDCAD* OUTPUT (SLOSS and CSTRS used)
SCNV15SD.OUT	SEDCAD* OUTPUT)SLOSS and CSTRS used)

* All files were prepared for November 15, 1989 storm event.

APPENDIX E

**NAMES AND ADDRESSES OF SUPPLIERS
OF SELECTED EQUIPMENT USED IN STUDY**

Names and Addresses of Manufacturers of Selected Equipment Used in Study

<u>Product</u>	<u>Supplier</u>
Flowmeter	Omega Engineering Inc. One Omega Drive Box 4047 Stamford, CT USA 06907-0047
Catchbasin	Coldstream Concrete Ltd. R.R.#2 Ilderton, ON N0M 2A0
Pressure Transducer	Honeywell Limited 300 Yorkland Boulevard North York, ON M2J 1S1
Radiometer	Li-cor Ltd. 4421 Superior Street P.O. Box 4425 Lincoln, NE USA 68504
Data Acquisition Programming Software	Campbell Scientific Canada Corp. 188 St. Clair Street Chatham, ON N7L 3J6

Simulation Software

AGNPS	Robert A. Young USDA-ARS North Central Soil Conservation Research Laboratory Morris, MN USA 56267
CREAMS	Walter G. Knisel USDA-ARS Southeast Watershed Research Lab P.O. Box 946 Tifton, GA USA 31793
SEDCAD*	Ms. Pamela J. Schwab Civil Software Design P.O. Box 11092 Lexington, KT USA 640512